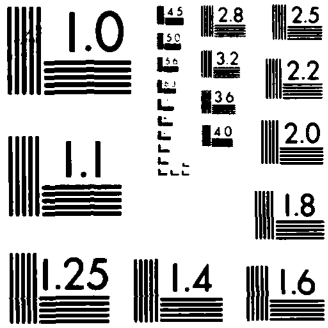
AD-A148 884 RELIABILITY AVAILABILITY AND MAINTAINABILITY OF THE HEAT RECOVERY INCINER..(U) NAVAL CIVIL ENGINEERING LAB PORT HUENEME CA J ZIMMERLE OCT 84 NCEL-TN-1709

1/1

UNCLASSIFIED F/G 13/1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963 A

(12)

AD-A148 884

TECHNICAL NOTE

TN NO: N-1709

TITLE: RELIABILITY, AVAILABILITY, AND MAINTAINABIL'TY OF THE HEAT RECOVERY INCINERATOR AT NAVAL AIR STATION JACKSONVILLE

AUTHOR: J. Zimmerle

DATE: October 1984

SPONSOR: NAVAL FACILITIES ENGINEERING COMMAND

PROGRAM NO: YO817-006-01-211

NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

Approved for public release; distribution unlimited.

84 12 27 008

METRIC CONVERSION FACTORS

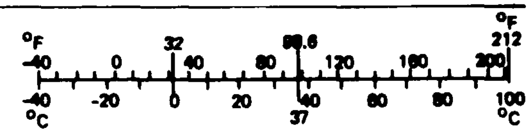
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeter	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TN-1709	2. GOVT ACCESSION NO. DN787114	3. RECIPIENT'S CATALOG NUMBER AD-A148 884
4. TITLE (and Subtitle) RELIABILITY, AVAILABILITY, AND MAINTAINABILITY OF THE HEAT RECOVERY INCINERATOR AT NAVAL AIR STATION, JACKSONVILLE		5. TYPE OF REPORT & PERIOD COVERED Final; June 1982 - May 1983
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J. Zimmerle		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS NAVAL CIVIL ENGINEERING LABORATORY Port Hueneme, CA 93043		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 63721N, YO817-006-01-211
11. CONTROLLING OFFICE NAME AND ADDRESS Chief of Naval Material Washington, DC 20350		12. REPORT DATE October 1984
		13. NUMBER OF PAGES 82
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

A-1

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Heat recovery incinerator, solid waste, waste to energy, RAM analysis, reliability, availability, maintainability, energy conservation landfills

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The performance of the Heat Recovery Incinerator (HRI) at Naval Air Station (NAS) Jacksonville, Fla., was studied from June 1982 to May 1983. The study included RAM (reliability, availability, maintainability) analysis of hardware components and five functional missions: (1) processing and incinerating waste and producing steam; (2) processing and incinerating waste; (3) incinerating waste; (4) incinerating waste and producing steam; and (5) combusting fuel oil and producing steam. Eight operational variables were monitored that included: waste generation rate, processing rate, incineration rate, ash production, landfill—

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

DTIC COPY INSPECTED 4

20. Continued

reduction, energy parameters, processing time, and incineration time.

The HRI performed only two of its five missions (2 and 3) during the test period because no steam was produced. Principal problems were failures of the hydraulic system, boiler water level controls, and storage system. Dust contamination and waste jams necessitated a number of maintenance actions. The HRI was excessively labor intensive which caused the NAS Jacksonville Command to shut down the HRI following the study.

The types of design, operation, and maintenance problems that occurred at the facility are discussed, and recommendations are made to correct these problems in future designs.

Library Card

Naval Civil Engineering Laboratory
RELIABILITY, AVAILABILITY, AND MAINTAINABILITY OF THE HEAT RECOVERY INCINERATOR AT NAVAL AIR STATION, JACKSONVILLE (Final), by J. Zimmerle

TN-1709 82 pp illus October 1984 Unclassified

1. RAM Analysis 2. Heat Recovery Incinerators I. YO817-006-01-211

The performance of the Heat Recovery Incinerator (HRI) at Naval Air Station (NAS) Jacksonville, Fla., was studied from June 1982 to May 1983. The study included RAM (reliability, availability, maintainability) analysis of hardware components and five functional missions: (1) processing and incinerating waste and producing steam; (2) processing and incinerating waste; (3) incinerating waste; (4) incinerating waste and producing steam; and (5) combusting fuel oil and producing steam. Eight operational variables were monitored that included: waste generation rate, processing rate, incineration rate, ash production, landfill reduction, energy parameters, processing time, and incineration time.

The HRI performed only two of its five missions (2 and 3) during the test period because no steam was produced. Principal problems were failures of the hydraulic system, boiler water level controls, and storage system. Dust contamination and waste jams necessitated a number of maintenance actions. The HRI was excessively labor intensive which caused the NAS Jacksonville Command to shut down the HRI following the study.

The types of design, operation, and maintenance problems that occurred at the facility are discussed, and recommendations are made to correct these problems in future designs.

CONTENTS

INTRODUCTION

The Naval Facilities Engineering Command (NAVFAC) tasked the Naval Civil Engineering Laboratory (NCEL) to evaluate heat recovery incinerator (HRI) technology for application at Naval shore facilities. As a part of this project, NCEL studied the long-term performance of the HRI at Naval Air Station (NAS) Jacksonville, Florida. The study was conducted to determine any changes necessary to improve existing HRI performance and to provide guidance for future HRIs of this type.

BACKGROUND

Heat recovery incineration is a developing technique for converting the combustible portion of solid waste into usable energy through the production of steam. The economic benefits from using HRI technology are dependent on the savings obtained from reducing fossil fuel use and from reducing the quantity of disposable solid waste.

The Navy has 591 installations worldwide (Ref 1) that generate an estimated 1.7 million tons of solid waste per year, of which approximately 85% is combustible (Ref 2). If these materials were recovered in the form of waste heat, 8,300,000 MBtu, or 1.4 million barrels of oil equivalent (BOE), would be available to offset fossil fuel utilization.

The Navy paid \$9.27/MBtu of steam in 1982 (Ref 3). Collection and disposal costs for solid waste averaged \$34/ton in 1982 (\$18/ton to collect, \$16/ton to dispose) (Ref 4), and the costs may double within the next 10 years (Ref 2) because of limited landfill space and legislative restrictions.

RAM analyses are used to mathematically predict or verify the performance of an equipment system, and represent a valid approach for determining the problems that have prevented HRIs from achieving their potential. The application of RAM study techniques to the NS Mayport HRI was one of the first uses of RAM parameters to evaluate HRI technology (Ref 5).

The three RAM parameters are reliability, availability, and maintainability. These parameters are mathematically expressed as Equations A-2 through A-9 in Appendix A.

Reliability is expressed as the probability that an equipment system can complete a specified operational cycle without a failure occurring. Reliability is useful as an indicator of inadequate or degrading performance. In general, following installation and a shakedown phase, reliability should reach a steady-state value and then decay due to equipment aging. This decay is used to predict equipment replacement time or to indicate when repairs or adjustments will be needed. Changes in design could be indicated if steady-state values never reach acceptable limits.

Availability is expressed as the probability that at any point in time the system will be capable of performing its stated mission. Availability is a measure of the length of time that a system will be able to perform a given task under its mission. A low availability value means that adjustments or repairs are needed or that design changes are required. Availability decays in a similar fashion to reliability.

Maintainability is expressed as the total number of maintenance man-hours required for every hour of operation. Maintainability is an indication of the level of effort required to keep the system operational. A large value for maintainability means that maintenance is too complex; equipment is too old; or maintenance access to equipment is inadequate. In general, maintenance increases as equipment ages because more failures occur and more adjustments are necessary to maintain performance levels.

HRI AT NAS JACKSONVILLE

Description

The HRI at NAS Jacksonville was completed in December 1979 at a cost of $2.8 million. Operation began in June 1980, while testing started in June 1982. The HRI, shown in Figure 1, consists of six subsystems: receiving, processing, storage, incineration, ash, and boiler. The system was designed to operate as described below.

Receiving Subsystem. The collected waste enters the receiving subsystem and is deposited on the tipping floor, where the waste is manually sorted to remove large pieces of metal; bulky, dangerous items; and other materials that interfere with HRI operation. After sorting, a front-end loader pushes the waste onto the conveyor belt that moves the waste to the processing subsystem.

Processing Subsystem. The processing subsystem converts the raw waste into a homogeneous fuel with a reduced ash content and an increased energy value at a rate of 5 tons/hr (TPH) for 8 hours/day. The homogeneous fuel is expected to improve HRI operation by allowing a more efficient burning rate, and by removing material which may damage HRI equipment such as metals, glass and rocks. There are five major equipment systems in the conversion process: a flail mill, a magnetic separator, a trommel screen, a cyclone separator, and an industrial shredder. Two support systems consist of a series of belt conveyors to transfer waste between the different processes, and a dust filter that cleans the air from the cyclone separator before venting it to the atmosphere.

The first piece of equipment, the flail mill, reduces the size of the incoming waste to 8 to 12 inches and breaks up boxes and plastic bags. The flail mill has a maximum design capacity of 10 TPH and an average capacity of 5 TPH. The flail mill discharge is then passed underneath an air scoop that removes the lightweight waste fractions to the cyclone separator.

The remaining waste is then sent through a 10-TPH (maximum) magnetic separator that removes ferrous metals. This step reduces the quantity of noncombustibles in the waste.

Next, the waste enters a 10-TPH (maximum) trommel screen that removes the waste fraction that is less than 3/4 inch in size. This step removes most of the glass and dirt from the waste, thus again reducing the quantity of noncombustibles. The remaining waste is then conveyed to the storage bin.

The lightweight waste fraction collected by the air scoop enters a cyclone separator. The cyclone separator system separates the dust, paper, and plastics from the flail mill discharge, thereby reducing the dust loading in the facility and improving the effectiveness of the trommel and magnetic separators. The light fraction is added back to the waste stream after the trommel discharge.

Finally, a 5-TPH (maximum) industrial shredder breaks up any hand-sorted, over-sized waste that cannot be processed by the flail mill. The shredder reduces the waste to less than 12 inches in size. The shredder discharge is added to the waste stream entering the magnetic separator.

Storage Subsystem. The final product from the processing subsystem is called a fluff Refuse Derived Fuel (RDF) and is conveyed to the storage subsystem which consists of a storage bin, screw augers, and conveyors to the incinerators. The storage bin has a 29-ton capacity for a waste density of 7 lb/ft^3. The waste is added to the top of the bin, and discharged from the bottom by a pair of counter-rotating screw augers that traverse the length of the bin. The augers move an average of 2 TPH or a maximum of 3 TPH of waste onto the conveyors to the incinerator subsystem.

Incinerator Subsystem. The incineration subsystem consists of three Comptro-Sunbeam packaged modular incinerator units, Model A-48. Each unit burns a maximum of 1 ton of waste per hour with two units operating and one on standby. The waste from the storage bin passes along a series of conveyors and is emptied into a feed hopper for each incinerator. The waste in the feed hopper is pushed by a hydraulic feed ram into the primary combustion chamber where it is combusted at 1,400°F to 1,600°F, releasing gases and turning the waste into an inert ash. The gases enter the secondary combustion chamber where any remaining combustible matter is incinerated at 1,800°F; then the gases are passed into the boiler subsystem. The ash is removed by the ash subsystem.

Ash Subsystem. The burning waste is mechanically moved along the primary combustion chamber by two hydraulic ash rams. The feed ram and the two ash rams are at staggered heights. Each ram moves the waste to the next lower level of the chamber to mix the waste and allow a more thorough carbon burnout. The resulting ash then drops into a water-filled quench tank, where the ash is cooled and removed by a drag chain to an ash container. The ash container is periodically dumped at the local landfill.

Boiler Subsystem. The boiler subsystem for each incinerator consists of a single-pass water tube boiler, and a common blowdown tank and feedwater equipment. The hot gases from the secondary chamber are passed through the water tube boiler, cooled, and released to the atmosphere. The boilers were each designed to produce 6,280 pounds of 125 psig saturated steam/hr, with an energy value of 1,185 Btu/lb.

Operational Objectives

The HRI was designed to accomplish two basic objectives. The primary objective was to save landfill space by reducing the volume and weight of solid waste through incineration. The secondary objective was to recover energy in the form of low pressure steam from the combustion products of the incinerated solid waste. These tasks represent the two benefit producing functions of an HRI: landfill savings and fossil fuel offsets.

The HRI is in one of five modes or missions when it is operational. These missions represent the various combinations of accomplishing the two design tasks. A numerical subscript on the results signifies which mission is represented (i.e., R_1 is the reliability for Mission 1).

A schematic representation of each mission is shown in Figure 2. The subsystems required to perform the mission are indicated by boxes surrounding the name of the subsystem. The materials that the subsystem handles (input) or produces (output) are specified on the diagrams. The waste generator (activity), and the ultimate receivers of the HRI end products (activity - steam; landfill - rejects and ash) are also shown for each mission.

Mission 1. The first mission is the processing and incineration of solid waste and the concurrent production of steam. All of the subsystems must be operational to perform this mission. This mission is the preferred operating mode for the HRI, as both basic project objectives are being fulfilled.

The HRI for design conditions was expected to operate under Mission 1 with a mean time between failure (MTBF) of 184 hours; 34 failures/yr were anticipated (Appendix B). Expected performance of the HRI included a reliability of 53% and an availability of 90%. These expectations and goals were documented after HRI construction, and are based on technological assessment of installed equipment and components (Ref 6 and 7).

Mission 2. The second mission is to process and incinerate solid waste. For this mission all of the subsystems except for the boiler subsystem must be operational. Mission 2 serves as the backup mission to the primary task of the HRI in the event the boiler is not operational; thus, the landfill savings benefit can continue.

The HRI performance expected under Mission 2 is better than Mission 1 because fewer subsystems need to be operational. The MTBF was predicted to be 284 hours or 22 failures/yr (Appendix B). This corresponds to a reliability of 66%. Mission 2 values for availability were predicted to be 90% (Ref 7).

Mission 3. The third mission is to incinerate solid waste only. For this mission, only the receiving, incinerator, and ash subsystems need to be operational. The incinerator is fed directly from the tipping floor. Mission 3 serves as the second backup mission to satisfy the primary objective of the HRI if both the processing line and the boiler are down; the benefit of landfill savings is still achievable.

The HRI performance expected under Mission 3 is better than Mission 1 and 2 because fewer subsystems need to be operational. The MTBF was predicted to be 367 hours or 17 failures/yr (Appendix B). This corresponds to a reliability of 73%. Mission 3 availability would be 90%.

Mission 4. The Mission 4 objective is to incinerate solid waste to produce steam. This mission requires the receiving, incinerator, ash, and boiler subsystems to be operational. Mission 4 is the backup mission to the secondary objective of the HRI in the event the processing system is not operational. The benefits of this mission are landfill savings and fossil fuel offsets.

The expected HRI performance under Mission 4 is better than Mission 1 because fewer subsystems need to be operational. The MTBF was predicted to be 223 hours or 28 failures/yr (Appendix B). This corresponds to a reliability of 59%. Mission 4 availability would be 90% (Ref 7).

Mission 5. The Mission 5 objective is to produce steam by combusting fuel oil. For this mission, only the incinerator (but not the feed and ash rams) and the boiler subsystems need to be operational. Mission 5 is the second backup mission to the secondary objective of the HRI. The benefit of this mission is the production of steam when no solid waste is available or the HRI cannot incinerate waste. No fossil fuel offsets occur because fuel oil is used to produce the steam.

The expected HRI performance under Mission 5 is better than Mission 1 and 4 because fewer subsystems need to be operational. The MTBF was predicted to be 416 hours, or 15 failures/yr (Appendix B). The expected reliability was calculated as 76%. The corresponding availability would be 90% (Ref 7).

Operational Parameters

Eight additional parameters were considered important in judging HRI performance. These parameters are: waste generation rate, processing rate, incineration rate, ash production, landfill reduction and cost savings, energy parameters, processing time, and incineration time. These parameters were used to define the predicted performance and logistics required to utilize the HRI and to determine changes in the areas of planning, design, operation, and maintenance that would improve future HRI performance.

Activity Waste Generation Rate. Activity waste generation rate is expressed as an average solid waste quantity produced by the activity in tons per day (TPD). The activity was predicted to generate 40 TPD (Ref 8).

Processing Rate. The processing rate is expressed as tons of solid waste that enter the processing subsystem per hour. This parameter is a design value that is based on the quantity of waste generated by the activity. The design value was predicted to be 5 TPH (maximum), which would be sustained for an 8-hour day (Ref 8).

Incineration Rate. The incineration rate is expressed as tons of solid waste incinerated per hour. This parameter is a design value based on the quantity of waste generated by the activity. Each incinerator was designed to burn 1 TPH of waste. Therefore, the total HRI design value was determined to be 3 TPH (maximum for three units) with an average 1.67 TPH (for two units) based on the 40 TPD input.

Ash Production. Ash production is measured as tons of wet ash produced per ton of waste incinerated. This parameter is a performance value based on the ash content of the incinerator feed (solid waste) and the effectiveness of the incineration process. The predicted value was 0.08 ton of dry ash per ton of solid waste incinerated or 0.13 TPH (Ref 8), based on a 1.67-TPH incineration rate and an 8% ash content.

Landfill Use Reduction and Cost Savings. Landfill use reduction is a measure of HRI effectiveness in completing the primary task of the HRI. The parameter is expressed as a percentage equal to the decrease in the quantity of waste landfilled. Landfill reduction is used to determine the annual cost savings from incinerating the waste. The expected value is 70% of the waste accepted at the facility (Ref 7) would be destroyed, with a projected disposal cost savings of $51,000/yr (200 ton/wk; $7/ton).

Energy Parameters. Energy parameters are measured in two forms: the percentage of energy supplied to the HRI from solid waste, and the potential fossil fuel offsets expressed as barrels of oil equivalent (BOE) saved per week. These parameters are performance values based on the energy available and the effectiveness of the energy conversion process. The predicted value for percent energy supplied was 91% and for fossil fuel offsets was 150 BOE/wk (Appendix B).

Processing Time. Processing time is measured as the average length of time the HRI is processing solid waste. This parameter is related to availability and represents the processing time that can be sustained by the HRI. The parameter is expressed as hours of operation per week for processing solid waste. The design value was 40 hr/wk for a 5-day week (Ref 8).

Incineration Time. Incineration time is measured as the average time the incinerators are burning solid waste. This parameter is related to availability and represents the incineration time that is sustained by the HRI. The parameter is expressed as hours of operation per week for incinerating solid waste. The design value was 120 hr/wk for a 5-day week (Ref 8).

Subsystem Operational Parameters

Each subsystem was designed to accomplish a different function. The receiving subsystem was designed to transfer 40 TPD through a 400 ft^2 area to the processing and incineration subsystems. The processing subsystem was designed to process 40 TPD of waste into a low ash, high Btu fuel over an 8-hour day. The storage subsystem can hold 29 tons of waste which can be transferred to the incineration subsystem at a maximum rate of 3 TPH and an average rate of 1.67 TPH.

The incineration subsystem was designed to burn at an average rate of 1.67 TPH (two units) and a maximum of 3 TPH (three units), producing 0.13 and 0.24 TPH of ash, respectively (dry basis). The maximum ash removal rate from the quench tank was predicted to be 0.5 TPH. Waste incineration was to be stopped if the ash removal subsystem broke down

to prevent ash buildup in the quench tank. Finally, each boiler was designed to produce 6,280 pounds of 125 psig saturated steam per hour with an energy content of 1,185 Btu/lb.

TECHNICAL APPROACH

Data Collection

This RAM study was based on data collected for operating times and maintenance actions (failures plus other actions). Operating time was the total time an HRI, subsystem, or mission was functional. Maintenance actions were equal to the total number of failures and other actions that occurred. Failures were defined as any event that caused an HRI, subsystem, or mission to be shutdown and required a repair (e.g., a part replacement) to correct. Other actions were those events that caused a shutdown, but occurred due to the need to adjust, calibrate, or unjam a piece of equipment.

The data required for this study were collected from June 1982 to May 1983 by plant personnel using two different datasheets and the procedures listed in Appendix C. The first datasheet is an Equipment Status Log (Figures C-1 and C-2 of Appendix C) that was used to record the operation, maintenance, and operational status of all HRI equipment during 1 week of operation. This first sheet was filled out at the end of each shift and described any equipment failure or repair that occurred and the manpower expended to correct the failure. The status of each piece of equipment was noted in terms of being operational, on standby, needing repair, etc. The sheet was also used to determine the various equipment operating and maintenance time categories.

The second datasheet, Consumables and Run Time Log (Figure C-3), was used to record weekly solid waste, fuel, and water consumed; equipment operating time; and ash removal.

The data were collected by plant personnel through a series of meters, scales, and HRI records/datasheets. Totalizing meters were used to record makeup water to the boilers, blowdown, and steam. An accumulating watt-hr meter was used to record electrical power consumed by the facility. Runtime meters were provided for each HRI I.D. fan, the flail mill feed conveyor, the industrial shredder, the ash conveyor, and the storage bin inlet feed conveyor. Scales were used to weigh incoming waste, and outgoing trommel rejects, hand rejects, and wet ash containers. HRI records/datasheets were used to determine manpower and man-hours in operation and maintenance, and the type and cost of spare parts and consumables.

Raw Data Analysis

The data were divided into two 6-month sections to facilitate analysis. These results have been published as References 9 and 10. The data are summarized here in Tables 1 through 4. Table 1 lists the raw data by run time, consumables, solid waste, and boiler output categories, while Table 2 lists the raw data by subsystem categories. Table 3 presents the results for the subsystem analysis, while Table 4 contains the results of the mission analysis. Appendix A contains the theoretical analysis procedure for computing HRI performance.

The first step of the analysis procedure was to take the raw data from the datasheets and convert it into a useful form for parameter determination. The five principal conversion categories were: consumables, manpower, failures, other actions, and time.

The consumable raw data were determined from two consecutive Datasheets No. 2. The later sheet provided the final meter readings, while the first datasheet provided the initial meter readings. The final readings, minus the initial readings, gave the total quantity used, processed, or incinerated.

Data for manpower, failures, and other actions were taken directly from Datasheet No. 1. The information was obtained by reading the descriptions of equipment status, failures, and repairs that occurred, and assigning these events to the appropriate categories.

Time categories were the most difficult to determine and were based on the time periods noted on consecutive Datasheets No. 2. The basic operating time (t_a) for the subsystems and missions was found by subtracting the final and initial results from the run time meters. The routine and corrective maintenance times were found by taking the time differential between maintenance start and finish from Datasheet No. 1 based on the repair data assumptions. The remaining time in the period between each Datasheet No. 1 was placed into the idle time categories. Idle, but operational time (t_d) was used when the HRI had been operated but was idle due to a nonfailure shutdown, such as the weekend shutdown. Idle, but not operational time (t_e) was used when the HRI could not be operated due to a failure or need for a part replacement. The sum of the five time categories equaled the actual calendar time.

The second step of the analysis procedure involved the use of four data assumptions and three parameter substitutions to facilitate and complete the analysis.

The first assumption concerned floor feeding of the HRI. This assumption was required because very little information was given except to note when floor feeding occurred. It was assumed, therefore, that 15.7% of the waste received was fed directly into the HRI and that 22.7% of the total incineration time was floor-fed time. These numbers are averages based on the datasheets completed when data were recorded for direct feeding. The data in the processed and incinerated weight categories, and storage subsystem operating time were calculated using the floor-fed data. The processed weight equaled the received weight minus the hand-rejected weight minus the floor-fed weight. The incinerated weight equaled the processed weight minus the trommel-rejected weight plus the floor-fed weight. The storage operating time was not measured directly, so the storage time was estimated by subtracting the time that the incineration subsystem was floor fed (22.7% of total incineration time) from the total time the incinerator was operating. The result was the time the incinerator operated on stored waste.

The second assumption was that the waste generated by the activity equaled the waste received plus the waste not accepted by the facility. All the waste trucks were weighed at the HRI, but many were sent to the landfill. To determine the weekly average of solid waste generated, the only data used were from weeks when both accepted and not-accepted waste data were recorded. This assumed that NAS Jacksonville was still producing waste even though no waste was received at the HRI.

The third assumption was made in the category of equipment repair times. The repair times listed in Table 2 are estimated values based on equipment logs, discussions with HRI personnel, and data gathered previous to the test period or for similar pieces of equipment. These assumptions were necessary to determine the availability and maintainability parameters.

The fourth assumption was that the operational times for the processing subsystem could be based on the operating times for certain conveyors or pieces of equipment. Only the flail mill and the shredder were independently metered, so the other pieces of equipment and the processing subsystem were assumed to operate for the same length of time as the storage bin inlet feed conveyor.

The three parameter substitutions were inherent availability (A_i) for operational availability (A_o); maintainability ratio (MR) for maintainability index (MI); and mean time to repair (MTTR) for maintainability (M). The inherent availability (A_i) was a measure of the time spent actually operating or repairing the HRI. Because this time did not include any idle time waiting for repairs to begin, A_i had a larger value than A_o. The data collection procedure was originally set up to determine A_o of the HRI (see Appendix A) rather than A_i. However, due to a lack of data in the time categories, the alternate form of availability was substituted.

The second substitution occurred because man-hours of maintenance were not measured. An alternative, maintainability ratio (MR) in maintenance hours per operating hour, was therefore substituted for the predicted maintainability index (MI) in man-hours per operating hour.

The third substitution of MTTR for M occurred for the same reason as the second substitution: maintenance man-hours were not measured. The new parameter served as an alternate indication of the maintenance effort required to maintain the subsystems in an operational state.

Mission Analysis

The data requirements for determining the mission reliability and availability parameters were the reliability and availability parameters of each subsystem required to achieve that mission. The mission parameters (Table 4) were determined by multiplying the parameters for the appropriate subsystems (Table 3).

Operational Parameters Analysis

Activity waste generation was measured by taking the total solid waste received plus the total solid waste not accepted from Datasheet No. 2 and dividing by the number of weeks both sets of data were reported.

Processing rate was measured in TPH by dividing the total solid waste processed by the processing time in hours (Datasheet No. 2). This measurement is listed as Equation A-28 in Appendix A.

Incineration rate was measured in TPH by dividing the total solid waste incinerated by the incineration time in hours (Datasheet No. 2). This is expressed as Equation A-29 in Appendix A.

Ash production was measured in tons of ash per tons of solid waste, or in TPH, by dividing the weight of wet ash produced by the tons incinerated or the incineration time in hours (Datasheet No. 2). This is expressed as Equation A-31 in Appendix A.

Landfill use reduction was measured in percent as the quantity of waste sent to the landfill divided by the total quantity of waste accepted by the facility. The landfill waste was a combination of the hand rejects, trommel rejects, and wet ash listed in Datasheet No. 2. The cost reduction was equal to the quantity of waste received multiplied by the landfill use reduction and a $7/ton disposal fee. This is expressed as Equation A-32 in Appendix A.

Energy parameters were expressed as a percent for solid waste energy supplied to the HRI, and BOE saved per week for fossil fuel offsets. Solid waste energy supplied was determined by dividing the energy output from processed and floor-fed solid waste by the total energy input into the HRI as fuel oil and solid waste. Potential fossil fuel offsets were determined by subtracting the energy input as electrical power and front-end loader diesel fuel from the steam energy output by solid waste. This result was converted to BOE and divided by the number of weeks of the study. Actual results were not determined because no steam was produced. Therefore, these results will be used as a general indication of HRI operation.

Processing time in hours per week was measured by taking the total operating time for the flail mill feed conveyor and dividing by the total number of weeks for which data were recorded for the HRI.

Incineration time in hours per week was simply measured by taking the total operating time for the incinerator blowers and dividing by the total number of weeks data were recorded for the HRI.

Subsystem Analysis

Each of the subsystems was analyzed for consistent failures, maintenance actions, design problems, and good design features. The failures were determined from Datasheet No. 1 and were expressed as the number of failures for each piece of equipment. Design problems and features were determined from equipment analysis and interviews with plant personnel.

The subsystems were also analyzed for reliability, availability, MTTR, and operating/maintenance ratios. Failures and the maintenance effort (repair time) required to repair these failures were determined from Datasheet No. 1. The operating time was dependent on the subsystem being considered. The processing and receiving subsystems were expected to operate for 40 hr/wk; the other subsystems for 120 hr/wk.

The operating time for the receiving subsystem was not measured under the present procedure, and therefore no receiving RAM parameters could be determined. The processing and incineration subsystem times were measured by run time meters on the flail mill feed conveyor and the incinerator blowers, respectively. Storage subsystem operating time was equal to the incinerator time minus the time the incinerator was fed from the floor. The ash removal system and boiler operating times were measured by meters on the ash conveyor and Induced draft (I.D.) fans, respectively.

The operating time/repair time ratio was used as a measure of actual system performance. A large value indicated satisfactory operation. A small ratio indicated that a heavy maintenance burden was needed to keep the subsystem operational.

RESULTS

The results are separated into three major subsections: mission analysis, operational parameters analysis, and subsystem analysis. The actual and predicted results are compared in Table 5, and a percentage difference is shown. Recommendations on improving mission performance will be given as part of the Subsystem Analysis Results section.

Mission Analysis

Missions 1, 4, and 5. Missions 1, 4, and 5 were not accomplished over the study period because the boiler subsystem was not functional. Steam was not produced due to technical and administrative problems, which are discussed in the Boiler Subsystem section.

Missions 2 and 3. The HRI performed these two missions from June 1982 to May 1983. For Mission 2 -- processing and incinerating solid waste -- the reliability was 0.25, and the inherent availability was 0.69. Mission 3 -- incinerating solid waste only -- had a reliability of 0.51 and an inherent availability of 0.86. The reliability values for Missions 2 and 3 were 62% and 30% lower than the respective expected values of 0.66 and 0.73 (Table 5). The availability values for Missions 2 and 3 were 23% and 4% lower than the expected values of 0.69 and 0.86 (Table 5). The principal causes of the shortfall were equipment and design problems in the processing and incineration subsystems (see Subsystem Analysis).

Operational Parameters Analysis

Activity Waste Generation. NAS Jacksonville generated an average of 31.0 TPD of solid waste, and the HRI accepted an average of 7.3 TPD of this amount. The facility received 1,871 tons of solid waste, while another 5,577 tons were sent to the facility but could not be accepted. Of the 1,871 tons, 1,439 were processed, 138 were rejected by hand sorting, and 294 tons were fed directly to the incinerators.

The 31.0 TPD generated by the activity was 22.5% lower than the predicted value of 40 TPD (Table 5). This shortfall would mean a substantial loss of revenue from a functional HRI and was caused by inadequate predesign planning. The pertinent studies were conducted for short periods of time (less than 2 weeks) by the HRI contractor. This length of time is statistically insignificant when compared to the long-term operation of the HRI. This was demonstrated by examining the large variation in solid waste generated over the study period. The quantity of waste varied from 621 to 995 tons/month or 25 to 40 TPD.

It is recommended that a comprehensive planning study be completed before an HRI design is begun. A planning study, such as that developed by NCEL (Ref 11), would provide accurate data on averages and variability of composition, quantity, and fuel characteristics of the activity waste. This is necessary to obtain the maximum economic potential and best design of the HRI. A proper study would also provide justification for any special equipment or procedures required to utilize the waste.

Processing Rate. The processing subsystem handled 1,439 tons of waste, producing 1,311 tons of incinerator feed and 128 tons of trommel/magnetic separator rejects. The processing rate was 2.1 TPH, which was 58% lower than the design rate of 5 TPH (Table 5). The shortfall was caused by the lack of space between, and the number of problems with, each piece of equipment.

Incineration Rate. The incineration subsystem burned 1,311 tons of processed waste and 294 tons of floor fed waste, producing 220 tons of wet ash. The incinerators averaged only 0.45 TPH compared to the expected system rate of 1.67 TPH. This 73% shortfall (Table 5) was due to the number of hydraulic system and ram failures in the incineration subsystem. These problems are discussed in the Incinerator Subsystem section.

Ash Production. The HRI produced an estimated 0.09 ton of dry ash per ton of waste incinerated from a measured value of 0.14 ton of wet ash/ton of waste. This was a 12% increase when compared to the 0.08 predicted dry ash value (Table 5). The increase in ash production was perhaps due to the use of floor-fed solid waste as 18% of the feedstock, which had an ash content of 15% (Appendix B).

Landfill Reduction and Cost Savings. The reduction in landfill waste was 1,385 tons or 74% of the waste accepted by the HRI. At a disposal cost of $7/ton, the HRI saved $9,700 in landfill costs, even though only 24% of the activity waste generated was accepted by the facility. The 74% reduction in landfill waste indicated the potential benefit of this process, especially in areas with high disposal costs or a lack of landfill space.

Energy Parameters. Of the total energy input to the HRI, 89% was from solid waste, as calculated in Appendix B. If steam had been produced, (actually, no fossil fuel offsets were produced) fossil fuel offsets would have been 29.4 BOE/wk. The solid waste energy supplied value was approximately the same as predicted; and the potential fossil fuel offsets were 80% lower than the predicted values (Table 5). The shortfall in potential fossil fuel offsets resulted from the lower quantity of waste generated and the various equipment problems that occurred in the incinerator subsystem.

Processing Time. The processing subsystem averaged 13.2 hr/wk of operation which was 67% lower than the design value (Table 5). The main causes of the shortfall were shortage of waste, equipment problems, inadequate space between pieces of equipment, and dust control. These problems are discussed in the Processing Subsystem section.

Incineration Time. The incinerators averaged 70.4 hr/wk of operation, which was 41% lower than the design value (Table 5). The main causes of the shortfall were equipment problems and a lack of available feedstock (see Storage Subsystem section).

Subsystem Analysis

The detailed analysis of this HRI system shows that the facility could not have adequately performed its intended tasks. The HRI had 108 maintenance actions which include 32 failures. Total repair time was 795 hours of preventive and corrective maintenance with 196.8 hours of repair time for the 32 failures. The problems were inherent to the system and not caused by the type of HRI facility. Therefore, the recommendations for HRI improvement are based on preventing deficiencies in future designs rather than correcting the number of problems at the NAS Jacksonville HRI.

Receiving Subsystem. RAM parameters for this subsystem were not determined because operating time data were not collected. The subsystem had a few typical problems with the front-end loader (flat tires, mechanical problems) and a major design problem with the small size of the tipping floor. The tipping floor had an area of 400 ft^2 to handle 7.3 TPD. This value was 76% smaller than the recommended value of 1,680 ft^2 based on 230 ft^2/TPD (Ref 5). This situation occurred because the building housing the facility was too small to include a processing line and an adequately sized tipping floor. In future designs it is recommended that a minimum of 230 ft^2/TPD of area be set aside for the tipping floor.

Processing Subsystem. The processing subsystem had the worst overall performance of the subsystems. The subsystem had a mean time between failure (MTBF) of only 61.2 hours with a corresponding reliability of 0.52. The inherent availability was 0.83. The processing rate was 2.1 TPH, which is 58% less than the design goal of 5 TPH (Table 5). Fifteen maintenance actions occurred which included 11 failures. Total maintenance time was 142 hours, with 51.4 hours spent on repairs of failed parts. Maintainability parameters were 4.7 hours for mean time to repair (MTTR), a maintainability ratio (MR) of 0.076 hr/operating hr, and a 5:1 ratio of operating time to total repair time.

The processing subsystem consisted of seven major equipment systems. Three equipment systems either did not operate or rarely operated during the study period. Two of these systems -- the cyclone separator and its support dust collector system -- were never operated because the cyclone separator did not work properly. The separator was very labor-intensive, requiring constant attention to operate and excessive maintenance to clear waste plugs. The waste plugs were caused by the waste discharge valve which was too small and by the large pieces of film plastic that initiated the plugs. If future separators are used, the design should be based on the waste types identified in a predesign waste composition study (Ref 11).

The third equipment system that rarely operated was the industrial shredder. The shredder drive motor was removed and installed on the flail mill to keep the flail mill operating, and the Public Works Department was not able to replace the motor for the shredder. Three design problems justified the cannibalization of the shredder. The first was that initially the shear pin yield strength was higher than the strength of the shredder teeth. This caused the teeth to break before the shear

pin would fail, thus necessitating expensive repairs. This situation should be reversed (teeth stronger than shear pins) to prevent unnecessary repairs and cost. The second problem was the 3- by 4-foot size of the loading chute. Many of the bulky items sorted from the waste (pallets, wooden forms) were larger than the loading chute, thus requiring extensive manual labor to break the items down into a size suitable for feeding to the shredder. These items were then often fed to the incinerator rather than to the shredder. To justify the use of a shredder and to determine equipment size and characteristics that match incoming waste characteristics, a preliminary study should be conducted (Ref 11). The third problem was the operation of the reversing mechanism on the shredder drive motor. This mechanism was designed to reverse the shredder action to free jammed items. Either the mechanism did not operate or did not indicate when a problem occurred because shredder teeth were broken under jammed conditions. Periodic checks of the mechanism and some type of indication that the mechanism has operated should be included in future designs.

All of the eleven processing subsystem failures occurred in the four remaining equipment systems. Seven of these failures occurred in the conveyor belt system with four belt breaks, one broken belt clip, one motor burnout, and one set of worn out idler roller bearings. The first five failures were wear-out types, indicating the need for a heavy duty belt conveyor or periodic equipment checks. The last two failures occurred in the first 6 months and were caused by dust contamination.

The processing of solid waste creates a large quantity of dust that coats machinery, causing overheating and abrasion. It is recommended that increased routine maintenance be conducted on the motors and bearings in the processing subsystem. This procedure was implemented in the last 6 months and seemed to work, as no dust failures occurred during this time. The reporting period, however, was too short to form definitive conclusions. It is recommended that better preventive maintenance practices be included in future designs.

Three other failures also occurred due to dust contamination as the magnetic separator electric motor burned out twice and the flail mill bearings wore out. The flail mill bearings were a persistent problem before and during the study period. An automatic lubricating system was installed in the last period which seemed to correct the bearing problem. The operating time, however, was too short to form definitive conclusions. The bearing lubrication system is recommended for future designs, while the motor dust contamination should be corrected by increasing the level of routine maintenance.

The final failure was a broken drive-belt on the trommel screen. This occurred as a result of a combination of wear and dust abrasion and could have been corrected through increased routine maintenance.

In addition to the mechanical problems, the processing system also had functional problems in the form of equipment jams (four other actions). The worst areas were the shredder discharge, and the trommel inlet and discharge. The system design included very severe space restrictions. As a result, clearances between adjacent pieces of equipment were inadequate, causing jams and making it more difficult to remove the jams, especially in the three problem areas. The jams required numerous shutdowns and extensive maintenance manpower to clear and then restart the system. It is recommended that future designs carefully evaluate clearance and space requirements to prevent these types of problems.

Design changes were required in the flail mill and the flail mill conveyor. The flail mill ejected material over the side barriers of the flail, creating a hazardous situation inside the facility. Additional protection was added to control the direction of the shredded waste. The flail mill conveyor was installed backwards and was too expensive to remove and reinstall; therefore, modifications had to be made so that the conveyor could operate correctly.

Overall, the processing subsystem performed poorly with eleven failures and four other actions over the study period. The primary problems were dust contamination and lack of space for proper equipment operation.

It is recommended that a dust control system using increased building ventilation and/or physically separating dust-producing areas from other equipment be added to future designs. These recommendations should reduce dust-related failures and the maintenance burden associated with preventing performance degradation from dust. Dust-related problems are easily corrected, and future processing system designs should perform better.

Storage Subsystem. The storage subsystem had the best overall performance of the six subsystems because it was underutilized during the study. The system had a MTBF of 2,778 hours, with a corresponding reliability of 0.96. The inherent availability was 0.97. The discharge rate was 0.47 TPH which is 16% of the 3 TPH design goal. Eleven maintenance actions occurred which included one failure. The failure was a broken conveyor belt similar to the processing subsystem failures. Total maintenance time was 76 hours with 25 hours spent on one failed part repair. Maintainability parameters were 25 hours for MTTR, 0.009 hr/operating hr for MR, and a 37:1 ratio of operating time to total repair time.

The storage subsystem experienced the fewest number of failures over the study period, but it has a number of operational and design problems that make this type of storage system unsuitable for future designs using shredded or raw waste. There are four design problems: inlet conveyor drive motor location, inlet conveyor discharge, bin capacity, and bin bottom discharge design.

The inlet conveyor drive motor is located on the side of the conveyor opposite the catwalk. This renders the motor inaccessible to any routine or corrective maintenance procedures. Future designs should ensure that access is readily available to the conveyor drive motor and any other piece of equipment requiring periodic or emergency maintenance.

The inlet conveyor discharge created another problem in that the conveyor ends at a fixed point. This creates a large pile of waste which is not easily distributed throughout the bin. The concentration of waste causes the screw augers to jam, and if the waste pile is too high, the waste backs up on the conveyor. The system originally had a spreader mechanism but it did not work and was removed soon after the HRI was opened. HRI personnel had to manually spread the waste pile out and slow down the screw augers and auger drive to discharge the waste from the bin. The combination of screw augers and a set inlet discharge point should be avoided in future designs.

The storage bin capacity, which is 29 tons, was barely adequate at the design waste generation rate of 40 TPD or 1.67 TPH. The incinerators would empty the bin and be nonoperational if waste deliveries were late, quantity fluctuated, or a breakdown in the processing subsystem occurred. It is recommended that future designs be based on having a sufficient capacity to accommodate for changes in waste generation rates and equipment problems.

The final design problem was that the bin sides are open at the bottom to allow the traversing of the screw auger drive assembly. The openings allow solid waste to escape from the bin, thus clogging the gears and chains of the drive assembly. The clogging slows the drive movement, causes jams, and causes the drive assembly to jump off the chain. This type of design should be avoided in the future.

In addition to the design problems, there were operational problems with the storage subsystem. Long, stringy waste materials would wrap around and jam the augers, requiring extensive manpower to clear the jam. If a large waste pile were formed, the drive carriage of the screw auger would slow down or have to be manually controlled to prevent damage to the drive motor. This procedure is labor-intensive and reduces the discharge rate from the bin.

The overall effect of these design and operational problems was to reduce the discharge rate to only 16% of design. Combined with the labor-intensive nature of operating this storage subsystem, it is recommended that this type of storage bin not be used in future designs. A better design would be a below-ground storage pit and crane system.

Incinerator Subsystem. The incineration subsystem had the second worst performance of the six subsystems. The system had an MTBF of 224.5 hours, with a corresponding reliability of 0.59. The inherent availability was 0.91. The incineration rate was 0.45 TPH which is only 27% of the 2 TPH design goal (Table 5). Forty-four maintenance actions occurred which included 16 failures. Total maintenance time was 368 hours with 89 hours spent on part repair. Maintainability parameters were 5.6 hours for MTTR, 0.025 hr/operating hr for MR, and a 10:1 ratio of operating time to total repair time.

The incineration subsystem experienced the most failures over the study period; these failures are broken down into three areas: hydraulic system failures, failures due to excessive heat, and other failures.

Nine of the 16 failures occurred in the hydraulic system. The principal problem areas were hose breaks, cylinder failure, and a stuck-open relief valve. These failures averaged over 7 hours each to repair. The maintenance problem was due mainly to the inaccessibility of the hydraulic system equipment. The system was underneath the main floor and was only accessible through concrete covers that required two men to lift. One side of the unit was 4 inches from a wall, making repairs very difficult. Lighting was poor, and small pieces of solid waste that fell through holes in the concrete cover coated the unit. The filler caps for the hydraulic systems were covered by this waste, causing hydraulic oil contamination when the unit was refilled.

Hydraulic hose breaks accounted for six failures. The principal reasons for these were the length and routing of the hoses. Long hoses wear out faster from being dragged on the floor and from kinks and twists that damage the hose. The routing of the hoses allowed kinking

and abrasion problems to occur. In the last reporting period, many of the hoses were replaced with hard piping that eliminated hose failures, and the hydraulic power unit was moved up to the main floor which improved access for repairs. For future designs, it is recommended that the hydraulic system be on the main floor in a low dust environment with sufficient access for repair and maintenance; also hard piping should be utilized wherever possible.

Two of the nine hydraulic failures were caused by ram cylinder failures. In one case, the incinerator feed door was shut when the ram feed cylinder was activated. The resulting pressure bent the cylinder steel support beam beyond useful limits. Three changes would prevent this problem. The first would be the proper use of pressure relief valves set to prevent ultra-high pressures. The second would be an automatic control for the loading door and ram cylinder actions. (The HRI has such a system, but it did not perform reliably and had been turned off prior to this incident.) Third, the use of fastening bolts with a lower shear strength than the bending strength of the beam would cause the bolts to shear before the beam bent, preventing costly repairs.

The final hydraulic failure was a relief valve that stuck open. Routine maintenance of these units would reduce this kind of problem.

Three incinerator failures were caused by excessive or fluctuating HRI temperatures. A failed thermocouple and door warpage were caused by high primary chamber temperatures. Better controls would reduce this problem. Fluctuating temperatures due to inconsistent operation caused thin chips of refractory to break away from the HRI walls. This process is called spalling and can be prevented if HRI reliability and waste feedrate control (less temperature fluctuation) are improved.

The rest of the incinerator failures were unrelated. Three of the five failures occurred in the secondary chamber oil burner due to worn seals. The other two failures were a break in the incinerator feed belt and a fire under the incinerator access plates. More routine maintenance and better access to the equipment (secondary oil burner) would reduce these problems.

Twenty-eight maintenance actions also occurred that involved replacing hydraulic hoses before failure, unjamming ash and feed rams, and adjusting conveyors and the controls of the automatic feed door/ram cylinder control system. These maintenance actions were not failures and do not affect reliability. However, they do indicate the variety of problems that caused the poor performance of the incineration subsystem.

The incineration subsystem also had inadequate control of combustion air and was located outside of the facility. The leakage of air into the incinerators overwhelmed the combustion air control system, resulting in excessive temperatures and slagging. The incinerators and boilers were exposed to adverse weather conditions which made repairs more difficult and unsafe, and corroded the equipment.

Poor design, operation, and equipment failures were the main reasons for the poor performance of the incinerator subsystem. The hydraulic system, the feed and ash rams, and the lack of waste feedstock which caused inconsistent incinerator operation (temperature fluctuation) had major effects on incinerator performance. The incinerator did fulfill the primary mission of the HRI even with all of the performance problems. The 74% volume reduction in solid waste accepted shows the potential

benefits of this type of process if reliable performance can be sustained. By implementing the suggested recommendations in future designs, the incinerator reliability and landfill reduction performance should improve.

Ash Subsystem. The ash subsystem had the second best overall performance of the six subsystems. The system had an MTBF of 812.2 hours, with a corresponding reliability of 0.86. The inherent availability of the system was 0.94. The ash removal rate was 0.09 ton of dry ash/ton of waste incinerated, which was only 12% above the expected value (Table 5). Thirty-eight maintenance actions occurred, which included four failures. Total maintenance time was 209 hours with 31.4 hours spent on repairs. Maintainability parameters were 7.8 hours for MTTR, 0.010 hr/operating hr for MR, and a 16:1 ratio of operating time to total repair time.

All of the 38 maintenance actions occurred in the ash conveyor. The four failures involved breakage of shear pins, which were designed to prevent conveyor damage. In general, the shear pins operated correctly, failing before the conveyor was damaged. The 34 other actions, primarily conveyor jams or the chain leaving the sprocket, were caused by large chunks of unburned waste. This problem would be reduced if the incinerator were fed only processed waste, and large pieces of noncombustibles were prevented from entering the incinerator.

Two additional design changes would improve ash subsystem performance. The first would be to provide a separate ash conveyor for each incinerator. The existing design uses one ash conveyor to remove ash from all three incinerators. If the conveyor fails, solid waste incineration has to stop to prevent an overload of ash in the ash subsystem. Second, future ash subsystem designs should ensure that no moving parts of the conveyor enter water. This should reduce the potential for jams, and reduce the lubrication requirements of the conveyor. In general, the ash subsystem performed adequately. The problems with the performance of this subsystem can be corrected with the suggested design changes.

Boiler Subsystem. The boiler subsystem did not produce any steam during the study period. There were three reasons why the boiler subsystem never operated. The first was an inadequate automatic boiler water level control. The control system did not accurately measure the water level inside the boiler, thus preventing consistent production of the necessary quality and quantity of steam. Also, the boiler sightglass for manual water level control could not be seen from the water valve. Either two persons had to be used to adjust the level, or one person had to do both jobs. This was very time-consuming, as the water level needed constant adjustment. It is recommended that a more sophisticated control system be installed in future designs.

The second reason was a lack of access to the boiler tubes for maintenance or repair. Two small ports are available on each side of the boiler, but these are not adequate to reach all of the boiler tubes. Because of this, the boiler tubes were not cleaned and could not efficiently produce steam. It is recommended that easy access to all parts of the boiler be designed to ensure that proper maintenance and repair procedures can be accomplished.

The third reason was the spacing and the condition of the boiler tubes. The tubes were too closely spaced for the fly ash produced in the HRI. The spacing between the front tubes became clogged with ash,

restricting air flow through the boiler, and preventing steam production. Steam soot blowers were provided, but they may not have been able to operate properly under the ash loading and lack of access for ash removal. Also, the boiler tubes rusted from exposure because the boilers were not located inside the main building. It is recommended that all HRI equipment be located inside the main building to protect it from the weather, that boiler tubes be adequately spaced for the ash particle size and loading rates, and that soot blowers for the water tube boilers be properly installed, if required.

There were also three administrative reasons why the boiler subsystem did not operate. The first was the labor-intensive nature of producing steam due to water level control. The HRI was originally designed so that only one person was needed to supervise the automatic operation of the facility. Actually, two people are required to keep the boiler alone operating. Therefore, it was not cost-effective to operate the boiler subsystem.

Second, the Public Works Department had a limited number of personnel available for work at the HRI and the other boiler facilities. Due to the problems at the HRI, the manpower could more effectively produce steam at the conventional boiler facility.

The third reason was the quantity of HRI steam that could be produced. The HRI could only produce 12,000 lb of steam/hour which did not even meet the minimum requirements (18,000 lb/hr) for starting the steam pumps at the adjacent boiler facility. Future designs should ensure that the HRI be located adjacent to a facility where the steam can be utilized so that the full fossil fuel savings can be realized.

In summary, the boiler subsystem did not produce steam (the secondary task of the HRI) because of the extra manpower required to operate the system and because the HRI steam output did not meet minimum requirements for steam distribution circuitry. HRI boiler designs considered in the future should ensure proper access for maintenance and repair and that proper controls for automatic boiler operation are installed. Also, the HRI steaming capability should be utilized so that the maximum fuel savings potential is realized.

CONCLUSIONS

The HRI at NAS Jacksonville did not fulfill design performance at anytime over the study period. The principal reasons for the poor performance were inadequate design of the hydraulic system, boiler water level control system, and storage system. Dust contamination and waste jams caused a number of maintenance actions that shut down various subsystems or the entire HRI. The facility was unacceptably labor-intensive in operation, placing a strain on the resources of the NAS Jacksonville Public Works Department that ultimately led to the shutdown of the plant.

RECOMMENDATIONS

NCEL recommendations are organized into areas of planning, design, operation, and maintenance. These recommendations are primarily for design elements reviewed in this report, that should be carefully considered in an HRI being designed for any Navy facility.

Planning Criteria

- Prior to HRI design, conduct a long-term study to determine the variability of waste quantities and composition. This study should be conducted as outlined in Reference 11, which is a new solid waste survey method developed by NCEL. This method involves the collection of data for 25 to 30 days over a year's period and then analyzes the data statistically to provide accurate results. The benefit of this procedure is that the HRI can be properly designed for the type, quantity, and variability of waste available. This will reduce capital, operation, and maintenance costs, improve reliability, and justify the need for any particular type of special equipment.

Design Criteria

- The hydraulic system of the incinerator should be in a clean area that is easily accessible, with room for maintenance and repairs. Hard piping should be used wherever possible, and any hydraulic hoses required should be laid out in short lengths with no kinks or twists.

- The RDF storage system should be sized to accommodate normal solid waste deliveries for one or two days, as well as compensate for HRI downtime and variations in waste quantity. The configutation of the storage system can be a storage pit with crane removal. Do not use bottom-deployed screw augers to move raw or shredded waste.

- The boiler should have ready inside access to allow for ash removal, and maintenance and repair procedures. The boiler should also have reliable controls so that accurate automatic operation is possible, and that the required flow of steam at design enthalphy can be produced. Boiler tubes should be adequately spaced for the ash particle sizes and loading rates. Soot-blowing equipment for water tube boilers should be properly installed, if required.

- Any piece of equipment that is subjected to pressure or imposes pressures (hydraulic cylinders, shredder, flail mill equipment, or ash conveyors) should be designed with shear pins or pressure relief valves so that permanent damage cannot occur to support brackets or operating surfaces (e.g., shredder teeth).

- The tipping floor should have a minimum area of 230 ft^2/TPD to allow for effective handsorting and safe front-end loader movement.

- There should not be any kind of space restriction in the design of the facility. Adequate space for maintenance, repair, and waste movement from subsystem to subsystem is essential to ensure reliable operation of the HRI.

- Control instrumentation should be liberally included in the design to ensure reliable operating performance while providing alarms when problems develop (e.g., signals that shredder anti-jam mechanism has operated).

- HRI steam production capability should be matched with facility demand and circuitry such that the HRI capacity and, thus, fossil fuel savings can be fully utilized.

- Dust control and automatic lubrication systems, and/or physical enclosures for dust-producing areas are necessary to reduce maintenance requirements for motor and and other machinery bearings.

- All HRI equipment should be located inside the HRI building to prevent unnecessary equipment corrosion.

Operating Criteria

- Handsorting of waste should be utilized to remove bulky and hazardous items and HRI operators must conscientiously prevent input of any items missed by the floor crew. This will reduce HRI downtime caused by damage from these items.

- The HRI should be operated with a consistent input of waste to prevent temperature variation failures, such as refractory spalling and slagging.

Maintenance Procedures

- Slag should be removed and all of the boiler tubes cleaned weekly.

- All motors and bearings should be inspected and overhauled bi-annually to check for dust, to lubricate, and to correct any misalignment.

- Rams should be inspected bi-annually to correct warpage or misalignment.

ACKNOWLEDGMENTS

This study was a team effort with assistance from D. Brunner, Project Leader; S. Garg, P. Stone, and C. Kodres, Project Engineers; M. Lingua, Program Manager; and B. Hanson, Z. Parker, and D. Leipert of VSE Corporation, Oxnard, Calif. All the individuals contributed their expertise in developing the procedures and data analysis used in this work.

The raw data for the study were provided by NAS Jacksonville Public Works personnel, with the assistance of the NAS Jacksonville command and Mr. B. La Vassuer and R. Robinson of the Public Works Office.

REFERENCES

1. Statistical tables of military real property, Part 12, Naval Facilities Engineering Command, NAVFAC P-319. Alexandria, Va., Sep 1982.

2. Characterization of Navy solid waste collection and disposal practices, Civil Engineering Laboratory, Contract Report CR 80.003. SRI International, Menlo Park, Calif., Oct 1979. (AD No. A080322)

3. D.M. Hannemann. NAVFAC key point summary, Naval Facilities Engineering Command. Alexandria, Va., 16 Mar 1983.

4. J. Zimmerle. Solid waste generation and disposal at Naval Shore Facilities, an update, Naval Civil Engineering Laboratory, Technical Memorandum M-54-83-12. Port Hueneme, Calif., Jun 1983.

5. J. Zimmerle. Reliability, availability, and maintainability of the heat recovery incinerator at Naval Station Mayport, Naval Civil Engineering Laboratory, Technical Note N-1708. Port Hueneme, Calif., Oct 1984.

6. Reliability engineering analysis - Small scale heat recovery incinerator installations (NS Mayport and NAS Jacksonville), Naval Civil Engineering Laboratory, Contract Report CR 82.032. VSE Corporation, Oxnard, Calif., Sep 1982. (Contract No. N00123-82-D-0149)

7. M. Lingua and J. Zimmerle. Preliminary performance criteria for heat recovery incinerator using refuse as a fuel, Naval Civil Engineering Laboratory, Technical Memorandum M-54-82-16. Port Hueneme, Calif., Sep 1982.

8. M. Lingua. Comparative evaluation of solid waste characteristics at NAS Jacksonville and NS Mayport, Naval Civil Engineering Laboratory, Technical Memorandum M-54-82-01. Port Hueneme, Calif., Jan 1982.

9. Evaluation of the Naval Air Station Jacksonville heat recovery incinerator - June-November 1982, Naval Civil Engineering Laboratory, Contract Report CR 83.035. Oxnard, Calif., VSE Corporation, Aug 1983. (Contract No. N00123-82-0149)

10. Evaluation of the Naval Air Station Jacksonville heat recovery incinerator - December 1982 to May 1983, Naval Civil Engineering Laboratory, Contract Report CR 84.005. Oxnard, Calif., VSE Corporation, Dec 1983. (Contract No. N00123-82-0149)

11. J. Zimmerle, S. DeMonsabert, and A. Chatterjee. Waste assessment method - Phase II for Naval shore activities, Naval Civil Engineering Laboratory, Technical Note (in preparation). Port Hueneme, Calif., (ca. 1984).

LIST OF SYMBOLS/ACRONYMS

ACS	Average cost of steam, \$/MBtu
A_i	Inherent operational availability
A_o	Operational availability as a probability (see Equation A-9), expressed as a decimal
AP	Ash production (see Equation A-31), ton/ton incinerated
BOE	Barrels of oil equivalent
Btu	British thermal unit
CC	Total cost of consumable supplies not included in CF, \$
CF	Total cost of fuel used (fuel and waste oil, diesel, and electrical power), \$
CF_{FFO}	Conversion factor for fossil fuel offsets, 5.8×10^6 Btu/BOE
CMR	Corrective Maintenance Ratio (see Equation A-5), man-hr/operating hr
CP	Total cost of parts used in repair, maintenance, and replacement, \$
DA	Efficiency of the HRI to accept activity waste (see Equation A-27), %
DR	Efficiency of solid waste weight reduction through incineration (see Equation A-30), %
d_{df}	Density of diesel fuel, lb/gal
d_{fo}	Density of fuel oil, lb/gal
d_w	Density of make-up water, lb/gal
d_{wo}	Density of waste oil, lb/gal
E_t	Electrical energy supplied to the HRI (see Equation A-25), Btu
e	Base of Naperian log system (2.718)
e_t	Conversion factor, 11,600 Btu/kW-hr
FFO	Fossil fuel offsets, BOE

FF_B	Fossil fuel energy used by the boiler, Btu
FF_{HRI}	Fossil fuel energy used by the HRI, Btu
HRI	Heat recovery incinerator
H_{df}	Energy from diesel fuel supplied to front-end loader (see Equation A-24), Btu
H_{fo}	Energy derived from fuel oil and supplied to HRI (see Equation A-19), Btu
H_{hri}	Energy supplied to HRI (see Equation A-17), Btu
H_{sw}	Energy derived from solid waste and supplied to HRI (see Equation A-18), Btu
H_w	Energy derived from make-up water (see Equation A-21), Btu
H_{wo}	Energy derived from waste oil and supplied to the HRI (see Equation A-20), Btu
h_{df}	Higher heating value from diesel fuel, Btu/lb
h_{ff}	Higher heating value of floor-fed solid waste as received, Btu/lb
h_{fo}	Higher heating value from fuel oil, Btu/lb
h_s	Steam enthalpy, Btu/lb
h_{sw}	Higher heating value from processed solid waste, Btu/lb
h_w	Enthalpy of makeup water from standard tables, Btu/lb
h_{wo}	Higher heating value of waste oil, Btu/lb
ID	Induced draft fan
IR	Incineration rate (Equation A-29), TPH
LR	Efficiency in reducing landfill space for solid waste accepted at HRI (see Equation A-32), %
M	Maintainability
M_{ff}	Quantity of floor-fed solid waste, tons
M_o	Quantity of solid waste rejected by the facility, tons
M_1	Quantity of solid waste accepted by the HRI facility, tons
M_3	Quantity of solid waste that was hand-rejected, tons

M_{12} Processed solid waste fed to HRI, tons

M_{14} Wet ash removed, tons

M_{15} Steam produced over the monitoring period, pounds

M_{17} Make-up water consumed, gallons

M_{20} Fuel oil supplied to HRI, gallons

M_{21} Waste oil supplied to HRI, gallons

M_{22} Diesel fuel supplied to front-end loader, gallons

M_{24} Quantity of material rejected from the dust filters, tons

M_{25} Quantity of material removed by the trommel screen and the magnetic separator, tons

MBtu One million British thermal units

MI Maintainability Index (see Equation A-6), maintenance man-hr/operating hr

MR Maintainability Ratio, maintenance hr/operating hr

Mt_a Operating labor spent on the HRI during the period t_a, man-hr

Mt_b Maintenance labor spent on the HRI during the period t_b, man-hr

Mt_c Maintenance labor spent on the HRI during the period t_c, man-hr

MTBF Mean time between failures (see Equation A-2), hours

MTTR Mean time to repair (see Equation A-7), hours

MTBMA Mean time between maintenance action (see Equation A-8), hours

NAS Naval Air Station

NAVFAC Naval Facilities Engineering Command

NCEL Naval Civil Engineering Laboratory

N_f Number of failures that caused shutdown at the HRI or subsystem

N_{ma} Number of maintenance actions

N_r Number of repairs

NS Naval Station

PR	Processing rate of the HRI facility (see Equation A-28), TPH
PMR	Preventive Maintenance Ratio (see Equation A-4), man-hr/operating hr
R	Reliability as a probability (see Equation A-3), expressed as a decimal
RAM	Reliability, Availability, and Maintainability
RCRA	Resource Conservation Recovery Act
R_p	Total active repair time spent on corrective maintenance, hours
SCC	Specific consumable costs (see Equation A-14), \$/MBtu
SOM	Specific operating labor (see Equation A-10), man-hr/MBtu
SP	Efficiency of steam production (see Equation A-33), lb of steam/lb of solid waste
SPC	Specific part cost (see Equation A-13), \$/MBtu
SRM	Specific repairs and maintenance labor (see Equation A-11), man-hr/MBtu
STM	Specific total labor (see Equation A-12), man-hr/MBtu
T	Total monitoring period, hours
T_{kwh}	Electricity supplied to the HRI, kW-hr
TE	Overall thermal efficiency (see Equation A-16), %
TE_B	Energy conversion process efficiency - boiler
TE_{sw}	Energy conversion process efficiency - solid waste
t_a	Operating period (HRI, subsystem, or equipment), hours
t_b	Time spent in routine maintenance, hours
t_c	Time spent in repairs/replacements, hours
t_d	HRI idle time (operational), hours
t_e	HRI idle time (not operational), hours
t_m	Mission time for reliability calculations, 40 hours for the receiving and processing subsystems, 120 hours for the HRI and other subsystems
W	Labor wage rates, \$/hour

Table 1. Raw Data for NAS Jacksonville HRI From June 1982 Through May 1983

Parameter	First 6-Month Period							Second 6-Month Period							Total Study Period
	Jun	Jul	Aug	Sep	Oct	Nov	Total	Dec	Jan	Feb	Mar	Apr	May	Total	
Run Time (Hour)															
Flail mill	136	20	34	47	103	90	430	0	33	18	0	93	0	144	574
Shredder	41	0	0	0	4	20	65	0	0	2	0	5	0	7	72
Storage bin feed conveyor	195	19	38	54	83	109	498	0	39	20	0	110	6	175	673
Ash conveyor	327	171	430	543	520	404	2,395	0	278	108	26	415	27	854	3,249
Incinerator #1	687	129	119	184	52	10	1,181	0	0	0	0	0	0	0	1,181
Incinerator #2	0	148	233	252	419	390	1,442	0	294	120	57	429	69	969	2,411
Incinerator #3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ID fan #1	184	0	0	184	32	10	410	0	0	0	0	0	0	0	410
ID fan #2	0	0	158	252	61	265	736	0	294	120	57	114	0	585	1,321
ID fan #3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Boiler #1	45	0	0	0	0	0	45	0	0	0	0	0	0	0	45
Boiler #2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Boiler #3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Consumables															
Electricity (kW-hr)	27,360	11,400	18,000	17,040	16,920	19,800	110,520	2,520	12,240	9,840	7,320	20,320	6,040	58,280	168,800
Boiler feedwater (gal)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diesel fuel (gal)	150	90	85	90	105	105	625	0	60	75	30	120	60	345	970
Hydraulic oil (gal)	41	30	139	10	57	105	382	0	41	45	65	25	0	176	558
No. 2 fuel oil (gal)	3,754	1,763	1,968	2,475	1,542	1,463	12,965	0	1,510	693	724	3,655	503	7,085	20,050
Waste oil (gal)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solid Waste Data															
Solid waste received (tons)	348	74	165	229	307	240	1,363	0	166	45	0	281	16	508	1,871
Solid waste not accepted (tons)	406	291	603	392	378	394	2,464	219	362	680	729	714	409	3,113	5,577
Solid waste hand-rejected (tons)	41	3	13	15	20	25	117	0	9	5	0	6	1	21	138
Solid waste processed (tons) (received - floor fed - hand-rejected)	252	60	126	178	239	177	1,032	0	131	33	0	231	12	407	1,439
Magnetic separated and trommel-rejected (tons)	29	3	7	23	21	29	112	0	2	5	0	5	4	16	128
Solid waste stored (tons) (processed - trommel reject)	223	57	119	155	218	148	920	0	129	28	0	226	8	391	1,311
Solid waste fed from floor (tons) (15.7% of received)	54	12	26	36	48	38	214	0	26	7	0	44	3	80	294
Solid waste incinerated (tons)	277	69	145	191	266	186	1,134	0	155	35	0	270	11	471	1,605
Wet ash (tons)	17	22	18	48	37	35	177	0	13	18	0	8	4	43	220
Dust rejected (tons)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Outputs															
Blowdown (gal)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steam (lb)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2. Raw Data Categorized by Subsystem

[June 1982 through May 1983]

Parameter	First 6-Month Period					Second 6-Month Period					Total Study Period					
	Processing	Storage	Incin.	Ash	Boiler	Processing	Storage	Incin.	Ash	Boiler	Processing	Storage	Incin.	Ash	Boiler	Total
Operating time (hours)	498	2,033	2,623	2,395	-	175	745	969	854	-	673	2,778	3,592	3,249	-	-
No. of failures	7	0	9	2	-	4	1	7	2	-	11	1	16	4	-	32
No. of maintenance actions	11	8	32	33	-	4	3	12	5	-	15	11	44	38	-	108
Estimated total maintenance time (hours)	101	51	213	178	-	41	25	155	31	-	142	76	368	209	-	795
Failure repair time (hours)	36.4	0	54	14.4	-	15	25	35	17	-	51.4	25	89	31.4	-	196.8
Tons processed	1,032	920	1,134	177	-	407	391	471	43	-	1,439	1,311	1,605	220	-	-

Table 3. Results of the Data Analysis by Subsystem

[June 1982 through May 1983]

Parameter	First 6-Month Period					Second 6-Month Period					Total Study Period				
	Processing	Storage	Incin.	Ash	Boiler	Processing	Storage	Incin.	Ash	Boiler	Processing	Storage	Incin.	Ash	Boiler
Mean time between failures, MTBF (hr)	71.1	2,033	291.4	1,197.5	-	43.8	745	138.4	427	-	61.2	2,778	224.5	812.2	-
Mean time between maintenance actions, MTBMA (hr)	45.3	254.1	82	72.6	-	43.8	248.3	80.8	170.8	-	44.9	252.5	81.6	85.5	-
Reliability, R	0.57	0.94	0.66	0.90	-	0.40	0.85	0.42	0.76	-	0.52	0.96	0.59	0.86	-
Availability, A_i	0.83	0.98	0.92	0.93	-	0.81	0.97	0.86	0.96	-	0.83	0.97	0.91	0.94	-
Maintainability, MTTR (hr)	5.2	-	6	7.2	-	3.8	25	5	8.5	-	4.7	25	5.6	7.8	-
MR (maintenance hr/operating hr)	0.073	0	0.021	0.006	-	0.086	0.034	0.036	[illegible]	-	0.076	0.009	0.025	0.010	-
Operating time to maintenance time ratio	5:1	40:1	12:1	13:1	-	4:1	30:1	6:1	28:1	-	5:1	37:1	10:1	16:1	-
Processing rate, PR (tons/hr)	2.1	0.45	0.43	0.074	-	2.3	0.52	0.49	0.05	-	2.1	0.47	0.45	0.068	-

Table 4. Results of the Data Analysis by Mission[a, b]

[June 1982 through May 1983]

Parameter	First 6-Month Period			Second 6-Month Period			Total Study Period		
	Mission			Mission			Mission		
	2	3	1, 4, 5[c]	2	3	1, 4, 5[c]	2	3	1, 4, 5[c]
Reliability, R	0.32	0.59	-	0.11	0.32	-	0.25	0.51	-
Availability, A_i	0.70	0.86	-	0.65	0.83	-	0.69	0.86	-

[a]Mission 1 - Process and incinerate solid waste to produce steam - all subsystems operational.

Mission 2 - Process and incinerate solid waste - all subsystems operational except for boiler.

Mission 3 - Incinerate solid waste only - receiving, ash, and incineration subsystems operational.

Mission 4 - Incinerate solid waste to produce steam - receiving, incineration, ash, and boiler operational.

Mission 5 - Produce steam with fuel oil - incineration (minus feed and ash rams) and boiler operational.

[b]Mission reliability and availability are obtained by multiplying in each case the component values together to produce one value (i.e., first 6-month period reliability for Mission 2 = incin. R x ash R = 0.66 x 0.90 = 0.59).

[c]Boiler subsystem was never operational; therefore, these missions were not performed.

Table 5. Comparison Between Actual and Predicted Results

Parameter	Predicted Results	Actual Results	Difference (%)
Reliability, %			
Mission 1	53	--	--
Mission 2	66	25	-62
Mission 3	73	51	-30
Mission 4	59	--	--
Mission 5	76	--	--
Availability, %			
Mission 1	90	--	--
Mission 2	90	69	-23
Mission 3	90	86	-4
Mission 4	90	--	--
Mission 5	90	--	--
Activity waste generation, TPD	40	31.0	-22.5
Processing rate, TPH	5	2.1	-58
Incineration rate, TPH	1.67	0.45	-73
Ash production, ton/ton	0.08	0.09	12.5
Landfill reduction, %	70	74	5.7
Landfill cost savings, $/yr	51,000	9,700	-81
Energy parameters			
Solid waste, %	91	89	-2
Fossil fuel offsets, BOE/wk	150	29.4	-80
Processing time, hr/wk	40	13.2	-67
Incineration time, hr/wk	120	70.4	-41
Maintenance (MTTR), hr/failure			
Receiving Subsystem	10	--	--
Processing Subsystem	10	4.7	-53
Storage Subsystem	10	25	250
Incineration Subsystem	10	5.6	-44
Ash Subsystem	10	7.8	-32
Boiler Subsystem	10	--	--

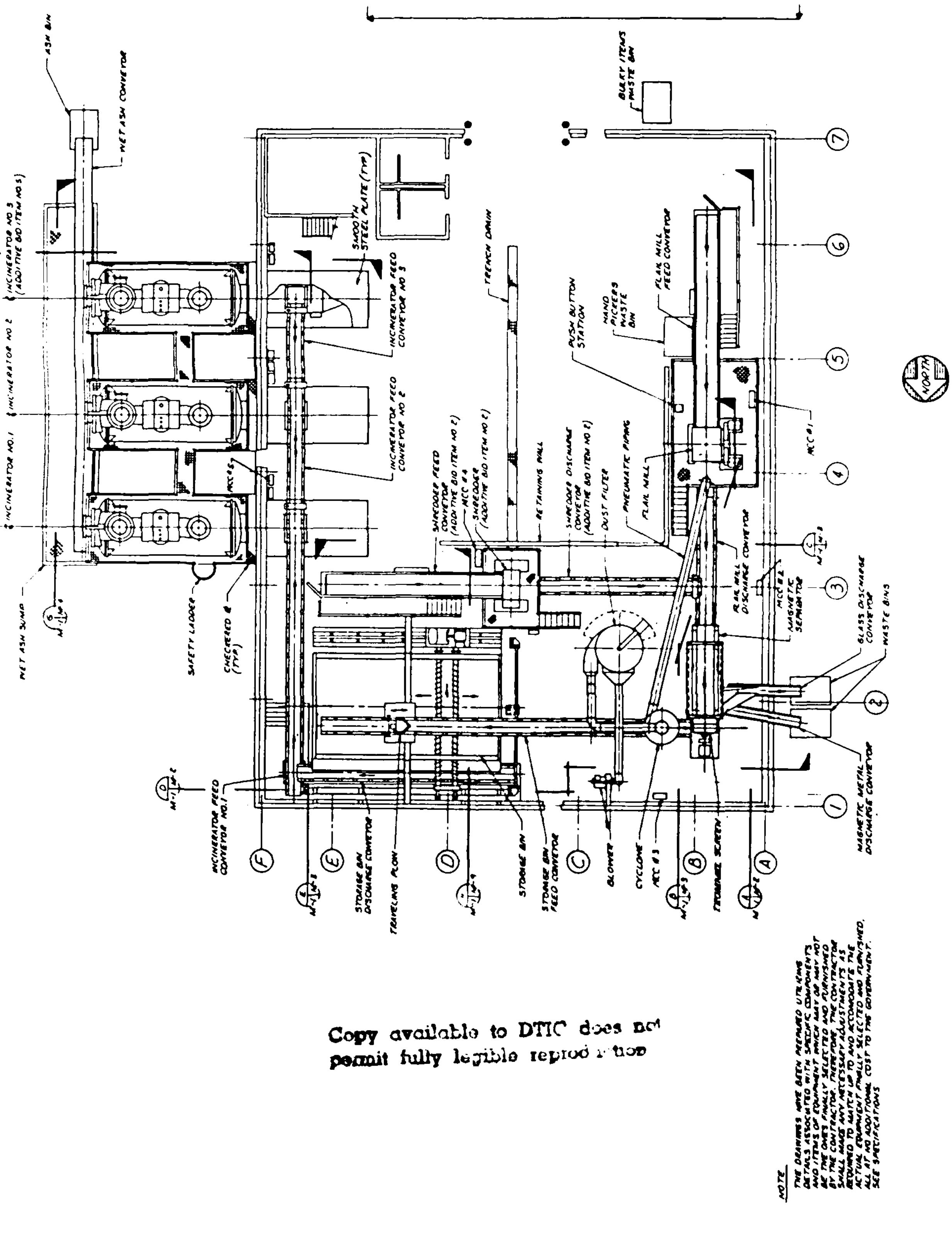
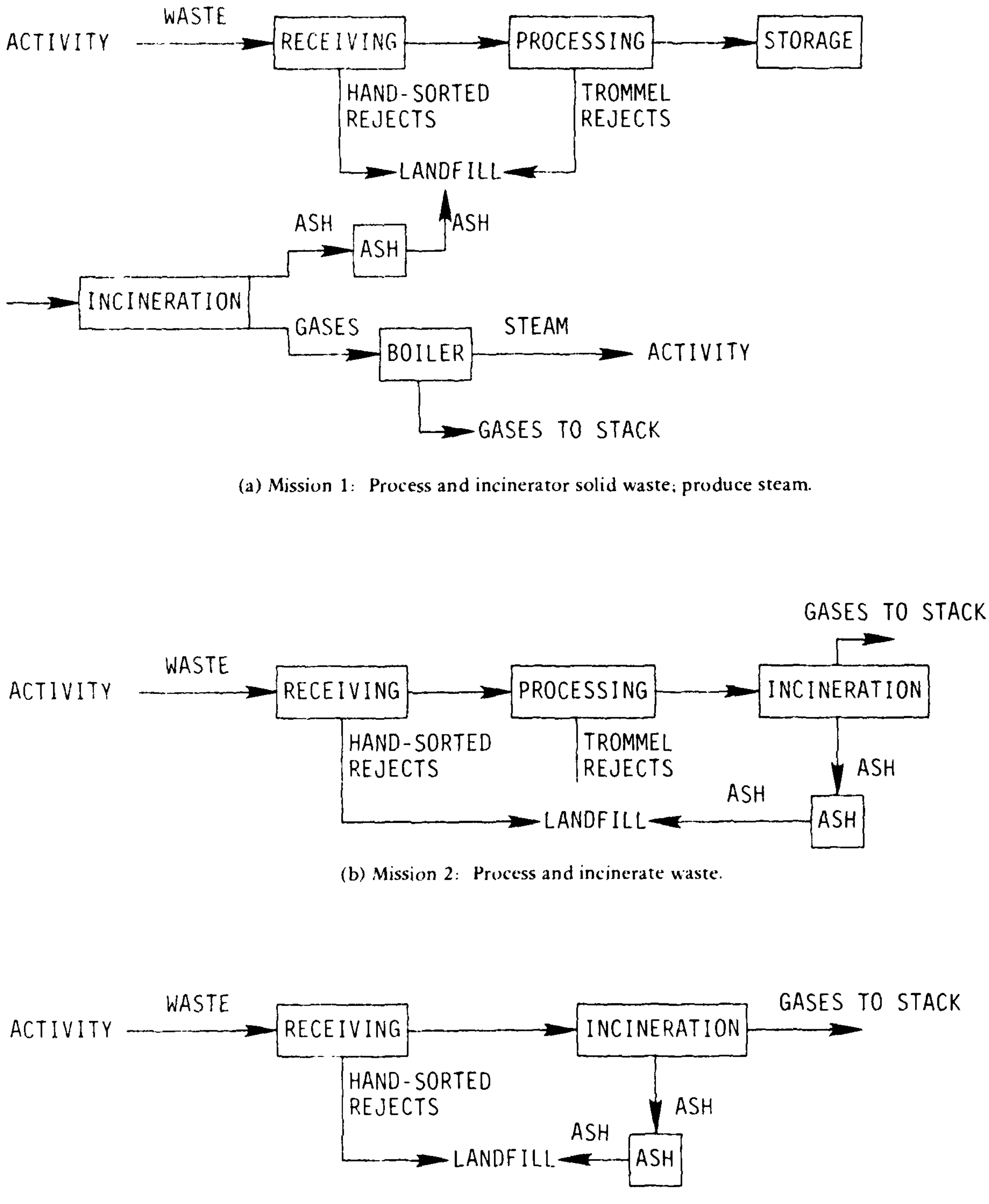


Figure 1. Layout of HRI at NAS Jacksonville.

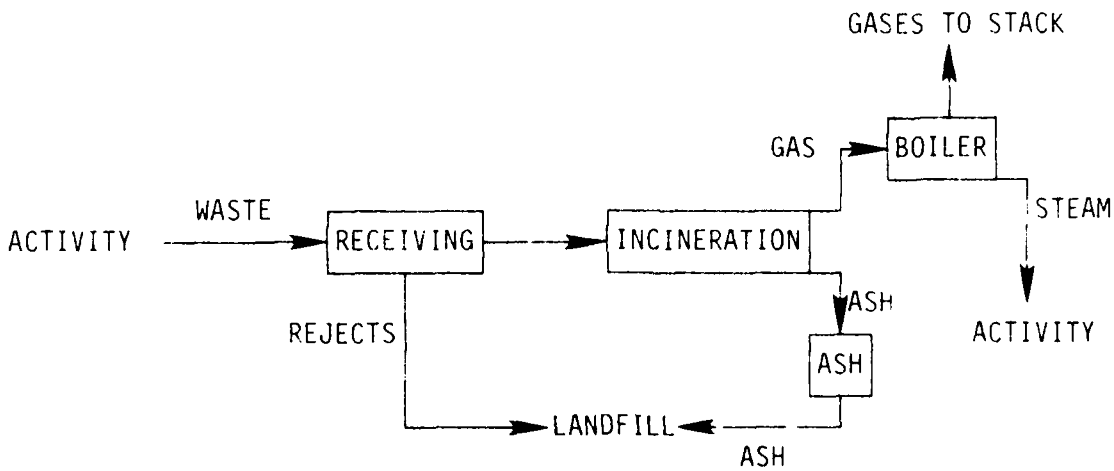


(a) Mission 1: Process and incinerator solid waste; produce steam.

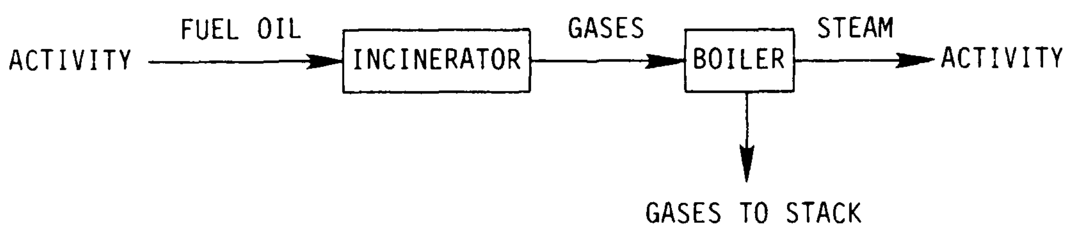
(b) Mission 2: Process and incinerate waste.

(c) Mission 3: Incinerate solid waste.

Figure 2. Schematic of the five missions.



(d) Mission 4: Incinerate waste to produce steam.



(e) Mission 5: Combust fuel oil to produce steam.

Figure 2. Continued.

Appendix A

PROCEDURE AND CALCULATIONS FOR RAM ANALYSIS

This appendix provides the definitions and formulas for the computation of RAM parameters, thermal efficiency, and cost for the complete HRI system.

TIME

The duration of HRI monitoring period, T, is divided into five distinct periods defined below:

t_a = HRI operating period, hours

t_b = time spent in routine maintenance, hours

t_c = time spent in repairs/replacements, hours

t_d = idle time when HRI is operational (but not used), and therefore, available, hours

t_e = idle time when HRI is not operational, and therefore, unavailable, hours

Subsystem (i.e., processing, incinerator, etc.) and equipment (i.e., flail mill, shredder, etc.) monitoring periods use the same breakdown of time for computing all RAM parameters. Then,

$$T = t_a + t_b + t_c + t_d + t_e \qquad \text{(A-1)}$$

t_a, <u>Operation Period</u>. This is the period over which the HRI or subsystem is actually operated during the monitoring period, T. It is determined by summing the run time of each start-up to shutdown cycle. This information is recorded on the Equipment Status Log.

t_b, <u>Routine Maintenance Period</u>. This is the period over which routine maintenance is carried out during the monitoring period. It is determined by summing the individual routine maintenance periods. When recording preventive maintenance time for computing preventive maintenance ratio (PMR), only scheduled or absolutely required preventive maintenance

is included. Preventive maintenance that is performed, but not required, during corrective maintenance periods or when the HRI is idle should not be counted when computing PMR. Each routine maintenance period is determined from data recorded on the Equipment Status Log.

t_c, Repair/Replacement Period. This is the period actually spent repairing the HRI or replacing components because of breakdowns, etc., during the monitoring period. It does not include time spent in procurement of components or in cooling the HRI to permit start of repairs or replacements. The total time spent in repairs/replacements over the monitoring period is determined by summing each repair/maintenance time from measurements recorded on the Equipment Status Log.

t_d, Idle Time Operational. This is the time when the HRI could be operated, if needed or desired, but is not operated for one or more of the following reasons:

1. Following routine maintenance shutdowns: From the time the routine maintenance is completed until the HRI is started for the subsequent operating cycle.

2. Following repair/replacement shutdowns: From the time the repairs or replacements are completed (also, completion of routine maintenance, if needed), until the HRI is started for the subsequent operating cycle.

3. During shutdowns for reasons other than routine maintenance and repairs/replacements: All the time spent in this shutdown mode counts toward operational idle time. Details are recorded on the Equipment Status Log.

t_e, Idle Time, Not Operational. This is the time between shutdown of the HRI for either routine maintenance or repairs/replacements and the beginning of routine maintenance or repairs/replacements, when the HRI is not operated. It includes time spent in cooling of the HRI to initiate routine maintenance or repairs/replacements, and time spent in procuring the parts of supplies while the HRI is not operating.

These measurements of t_a through t_e are used to make the calculations requiring time data.

RELIABILITY

Mean Time Between Failures (MTBF). MTBF is the average operating time until the occurrence of an equipment failure causes subsystem shutdown. It is calculated by dividing the total operating time by the number of failures. In simplified form,

$$\text{MTBF} = \frac{t_a}{N_f} \qquad \text{(A-2)}$$

where: MTBF = mean time between failure, hours

t_a = operating time (HRI, subsystem, or equipment), hours

N_f = number of failures that caused shutdown in the system or subsystem

Separate MTBF estimates are determined for each HRI subsystem and mission. This indicates the HRI's ability to systematically process and dispose of the solid waste received while recovering energy in the form of steam. It should be noted that operating times for the various subsystems vary.

Reliability as a Probability. Reliability is the most important of all the parameters. It is the probability that the equipment can perform its intended function satisfactorily over the duration of its mission when used in the manner and for the purpose intended while operating under the specified application and operational environment. Reliability is computed for various missions, including waste disposal and steam production. Reliability is expressed as:

$$R = e^{-t_m/MTBF} \tag{A-3}$$

where: R = reliability as a probability, expressed as a decimal

e = base of Naperian log system (2.718)

t_m = mission time. The scheduled period of operation of the HRI or subsystem; 40 hours for the receiving and processing subsystems, 120 hours for all the other subsystems and the HRI

MTBF = average number of hours of mission completed between failures. Computed from Equation A-2.

MAINTAINABILITY

Maintainability is expressed as the probability that an item will conform to specified performance requirements over a given period of time while maintenance actions are performed in accordance with prescribed procedures and resources. There are many measures of maintainability. For the HRI long-term evaluation, five measures of maintainability are used. These are defined as follows:

$$PMR = \frac{Mt_b}{t_a} \tag{A-4}$$

$$CMR = \frac{Mt_c}{t_a} \qquad \text{(A-5)}$$

$$MI = \frac{(Mt_b + Mt_c)}{t_a} \qquad \text{(A-6)}$$

where: PMR = preventive maintenance ratio, man-hr/operating hr

CMR = corrective maintenace ratio, man-hr/operating hr

MI = maintainability index, ratio, man-hr/operating hr

t_a = total operating time, hours

Mt_b = maintenance labor spent on the HRI during period t_b, man-hr

Mt_c = maintenance labor spent on the HRI during period t_c, man-hr

Mean Time to Repair (MTTR). MTTR is the average corrective maintenance time required to correct a failure. MTTR is estimated by dividing the total corrective maintenance time for a system by the number of equipment repairs. In simplified form,

$$MTTR = \frac{R_p}{N_r} \qquad \text{(A-7)}$$

where: MTTR = mean time to repair, hours

R_p = total active repair time spent on corrective maintenance, hours

N_r = number of repairs

Separate MTTR values are calculated for each HRI subsystem (i.e., Processing, Storage, Incineration, Boiler, and Ash Handling) as well as the heat transfer network and overall HRI.

Mean Time Between Maintenance Actions. MTBMA is the average operating time until the occurrence of a maintenance action. A maintenance action is initiated by an equipment failure or some other condition (i.e., out of alignment and requiring adjustment) whether or not the action results in a shutdown. MTBMA is calculated by dividing the total time (t_a) by the number of maintenance actions. In simplified form,

$$MTBMA = \frac{t_a}{N_{ma}} \quad \text{(A-8)}$$

where: $MTBMA$ = mean time between maintenance actions, hours

t_a = total operating time, hours

N_{ma} = number of maintenance actions

MTBMA estimates are provided for each HRI subsystem and the total system. It should be noted that each operating time is specific for the subsystem for which the MTBMA is being computed.

AVAILABILITY

Availability is generally defined as the probability that equipment will be capable of performing the specified function when called upon at any random point in time. Operational availability (A_o) provides the best measure for equipment in an operational environment.

For the HRI, A_o is defined as the ratio of the operating time to the sum of operating time and downtime over the monitoring period. In simplified form,

$$A_o = \frac{t_a}{t_a + t_b + t_c + t_e} \quad \text{(A-9)}$$

where: A_o = operational availability as a probability, expressed as a decimal

t_a = total operating time, hours

t_b = time spent in routine maintenance, hours

t_c = time spent in repairs/replacements, hours

t_e = HRI idle time (not operational), hours

A_o estimates are provided for each HRI subsystem and the total system.

STEAM COST

Computations are also necessary for establishing the cost of steam generated by the HRI. Equations A-10, A-11, and A-12 refer to specific man-hours rather than manpower costs for two reasons: (1) the labor

rate varies from year to year, and (2) the labor rates of base personnel are different from the labor rates charged by a contractor. Using man-hours data, the labor portion of the average cost of steam in Equation A-15 can easily be determined for subsequent years.

$$SOM = \frac{Mt_a \times 10^6}{M_{15} \times h_s} \qquad \text{(A-10)}$$

$$SRM = \frac{(Mt_b + Mt_c) \times 10^6}{M_{15} \times h_s} \qquad \text{(A-11)}$$

$$STM = SOM + SRM \qquad \text{(A-12)}$$

where: SOM = specific operating labor, man-hr/MBtu

SRM = specific repairs and maintenance labor, man-hr/MBtu

STM = specific total labor, man-hr/MBtu

M_{15} = steam produced over the monitoring period, pounds

h_s = steam enthalpy, Btu/lb

Mt_a = operating labor spent on the HRI during the period t_a, man-hr

Mt_b = maintenance labor spent on the HRI during the period t_b, man-hr

Mt_c = maintenance spent on the HRI during the period t_c, man-hr

$$SPC = \frac{CP \times 10^6}{M_{15} \times h_s} \qquad \text{(A-13)}$$

$$SCC = \frac{(CF + CC) \times 10^6}{M_{15} \times h_s} \qquad \text{(A-14)}$$

where: SPC = specific part costs, \$/MBtu

M_{15} = steam produced over the monitoring period, pounds

h_s = steam enthalpy, Btu/lb

CP = total cost of parts used in repairs, maintenance, and replacement, \$

SCC = specific consumable costs, \$/MBtu

CF = total cost of fuel used (fuel and waste oil, diesel and electrical power), \$

CC = total cost of consumable supplies not included in CF, \$

Then,

$$ACS = SPC + SCC + STM \times W \tag{A-15}$$

where: ACS = average cost of steam, \$/MBtu

SPC = specific part costs, \$/MBtu

SCC = specific consumable costs, \$/MBtu

STM = specific total labor, man-hr/MBtu

W = labor wage rates, \$/hr

THERMAL EFFICIENCY

The overall thermal efficiency of the HRI when firing solid waste and other fuels over the monitoring or any period of steaming is determined in the following manner:

$$TE = \frac{M_{15} \times h_s}{H_{hri}} \times 100 \tag{A-16}$$

where: TE = overall thermal efficiency, %

H_{hri} = energy from solid waste and other fuels supplied to HRI, Btu

M_{15} = steam produced over the monitoring period, lb

h_s = steam enthalpy, Btu/lb

H_{hri} is determined by adding the energy (in Btu's) derived from the various fuels consumed by the HRI. Equations A-18 through A-23 provide for the individual computation of heat from the various energy sources. In simplified form,

$$H_{hri} = H_{sw} + H_{fo} + H_{wo} + H_{w} \qquad \text{(A-17)}$$

where: H_{hri} = energy supplied to HRI, Btu

H_{sw} = energy derived from solid waste and supplied to HRI, Btu

H_{fo} = energy derived from fuel oil and supplied to HRI, Btu

H_{wo} = energy derived from waste oil and supplied to HRI, Btu

H_{w} = energy derived from makeup water, Btu

1. Energy derived from solid waste:

$$H_{sw} = (h_{sw})(M_{12}) \times 2{,}000 + (h_{ff})(M_{ff}) \times 2{,}000 \qquad \text{(A-18)}$$

where: H_{sw} = energy derived from solid waste and supplied to HRI, Btu

h_{sw} = higher heating value of processed solid waste, Btu/lb

M_{12} = quantity of processed solid waste supplied to HRI, tons

h_{ff} = higher heating value of floor-fed solid waste as received, Btu/lb

M_{ff} = quantity of floor-fed solid waste supplied to the HRI, tons

2. Energy derived from fuel oil:

$$H_{fo} = (h_{fo})(M_{20})(d_{fo}) \qquad \text{(A-19)}$$

where: H_{fo} = energy derived from fuel oil and supplied to HRI, Btu

h_{fo} = higher heating value of fuel oil, Btu/lb

M_{20} = fuel oil supplied to HRI, gal

d_{fo} = density of fuel oil, lb/gal

3. Energy derived from waste oil:

$$H_{wo} = (h_{wo})(M_{21})(d_{wo}) \quad \text{(A-20)}$$

where: H_{wo} = energy derived from waste oil and supplied to HRI, Btu

h_{wo} = higher heating value of waste oil, Btu/lb

M_{21} = waste oil supplied to HRI, gal

d_{wo} = density of waste oil, lb/gal

4. Energy derived from make-up water:

$$H_{w} = (h_{w})(M_{17})(d_{w}) \quad \text{(A-21)}$$

where: H_{w} = energy derived from makeup water, Btu

h_{w} = makeup water enthalpy from standard tables, Btu/lb

M_{17} = makeup water consumed, gal

d_{w} = density of makeup water consumed, lb/gal

FOSSIL FUEL OFFSETS

Fossil fuel offsets are calculated by subtracting the quantity of fossil fuels (fuel oil, electricity, and front-end loader diesel fuel) consumed by the HRI from the quantity of fossil fuels saved by the HRI. The fossil fuels saved are equivalent to the steam energy from solid waste divided by boiler efficiency. Equations A-22 through A-26 calculate the steam energy from each source and the estimated fossil fuel offsets.

1. Fossil fuel energy - boiler:

$$FF_{B} = (M_{15} \times h_{s})/TE_{B} \quad \text{(A-22)}$$

where: FF_{B} = fossil fuel energy used by the boiler, Btu

M_{15} = quantity of steam produced, lb

h_{s} = steam enthalpy, Btu/lb

TE_{B} = thermal efficiency of the boiler

2. Fossil fuel energy - HRI:

$$FF_{HRI} = H_{fo} + H_{df} + E_t + H_w \quad \text{(A-23)}$$

where: FF_{HRI} = fossil fuel energy used by the HRI, Btu

H_{fo} = energy derived from fuel oils (Equation A-19), Btu

H_{df} = energy derived from diesel fuel, Btu

E_t = energy derived from electricity, Btu

H_w = energy derived from makeup water, Btu

3. Energy derived from front-end loader:

$$H_{df} = (h_{df})(M_{22})(d_{df}) \quad \text{(A-24)}$$

where: H_{df} = energy of diesel fuel consumed by the front-end loader, Btu

h_{df} = higher heating value from diesel fuel, Btu/lb

M_{22} = diesel fuel consumed by front-end loader, gal

d_{df} = density of diesel fuel, lb/gal

4. Fossil fuel energy equivalent of electrical power supplied to the HRI:

$$E_t = (e_t)(T_{kwh}) \quad \text{(A-25)}$$

where: E_t = fossil fuel energy equivalent, supplied as electricity to the HRI, Btu

e_t = conversion factor, 11,600 Btu/kW-hr

T_{kwh} = electricity supplied to the HRI, kW-hr

5. Fossil fuel offsets:

$$FFO = (FF_B - FF_{HRI})/CF_{FFO} \quad \text{(A-26)}$$

where: FFO = fossil fuel offsets, BOE

FF_B = fossil fuel energy used by the boiler, Btu

FF_{HRI} = fossil fuel energy used by the HRI, Btu

CF_{FFO} = conversion factor for fossil fuel offsets, 5.8×10^6 Btu/BOE

OPERATIONAL PARAMETERS

1. Efficiency of the HRI to accept activity waste:

$$DA = \frac{M_1}{M_1 + M_o} \tag{A-27}$$

where: DA = efficiency of the HRI to accept activity waste, %

M_1 = quantity of solid waste accepted at the HRI facility, tons

M_o = quantity of solid waste not accepted by the facility, tons

2. Processing rate:

$$PR = \frac{M_1 - M_3 - M_{ff}}{t_a} \tag{A-28}$$

where: PR = processing rate of the HRI facility, TPH

M_1 = quantity of solid waste accepted by the HRI facility, tons

M_3 = quantity of solid waste that was hand-rejected, tons

M_{ff} = quantity of solid waste floor fed to the HRI, tons

t_a = processing subsystem operation period, hr

3. Incineration rate:

$$IR = \frac{M_{ff} + M_{12}}{t_a} \qquad \text{(A-29)}$$

where: IR = incineration rate of the HRI facility, TPH

M_{ff} = quantity of solid waste floor fed to the HRI, tons

M_{12} = quantity of processed waste fed to the HRI, tons

t_a = operating time of the incinerators, hr

4. Efficiency of solid waste reduction:

$$DR = \frac{M_{ff} + M_{12} - M_{14}}{M_{ff} + M_{12}} \qquad \text{(A-30)}$$

where: DR = efficiency of solid waste weight reduction through incineration

M_{ff} = quantity of solid waste floor fed to the HRI, tons

M_{14} = wet ash removed, tons

M_{12} = processed solid waste supplied to HRI, tons

5. Ash production:

$$AP = \frac{M_{14}}{M_{12} + M_{ff}} \qquad \text{(A-31)}$$

where: AP = wet ash production of the HRI, ton/ton

M_{14} = wet ash removed, tons

M_{12} = quantity of processed solid waste fed to the HRI, tons

M_{ff} = quantity of floor fed solid waste fed to the HRI, tons

6. Efficiency in reducing landfill space:

$$LR = \frac{M_1 - (M_3 + M_{14} + M_{24} + M_{25})}{M_1} \quad \text{(A-32)}$$

where: LR = efficiency in reducing landfill space for solid waste accepted at HRI

M_1 = quantity of solid waste accepted at HRI facility, tons

M_3 = quantity of solid waste that was hand-rejected, tons

M_{14} = quantity of wet ash removed, tons

M_{24} = quantity of material rejected from the dust filter, tons

M_{25} = quantity of material removed by the trommel screen and magnetic separator, tons

7. Efficiency of steam production:

$$SP = \frac{M_{15}}{M_{12}\ (2{,}000\ \text{lb/ton})} \quad \text{(A-33)}$$

where: SP = efficiency of steam production, lb of steam/lb of solid waste

M_{12} = solid waste supplied to HRI, tons

M_{15} = steam produced, lb

INSTRUMENTS/METERS

In order to collect the necessary data to perform the required calculations for reliability, maintainability, efficiency, and cost, the following meters/instruments are required. The instruments/meters are an integral part of the HRI and are used during tests and evaluations.

Run Time Meters

The run time meters used to determine the operating hours on various subsystems, equipment, and the HRI are itemized below with the quantity of meters in parentheses.

1. Boiler ID fans (3) - provide time producing steam.

2. Incinerator blowers (3) - provide time for burning.

3. Flail mill feed conveyor (1) - provides time for processing and for flail mill operation.

4. Industrial shredder (1) - provides time for processing and for shredder operations.

5. Ash conveyor (1) - provides time for incineration and ash handling.

6. Storage bin feed conveyor (1) - provides time for processing subsystem.

7. Storage bin outlet conveyor (1) - provides time for storage subsystem.

Watt-hr Meter

An accumulating watt-hr meter is used to determine the total electrical power supplied to the HRI facility.

Totalizing Flowmeters

Totalizing flowmeters are used to measure the makeup water (feedwater) to the boilers, blowdown, and steam.

APPENDIX B

CALCULATIONS FOR NAS JACKSONVILLE HRI

SOLID WASTE ENERGY SUPPLIED

The supplied energy over the monitored period was broken down into two parts, solid waste energy and auxiliary fuels energy. The proportion of each of these parts to the total energy supplied gave an indication of the relative importance of each part. Equations B-1 through B-8 calculated the heat derived from the four sources, the total energy supplied, and the relative proportions.

1. Energy derived from solid waste.

$$H_{sw} = (h_{sw})(M_{12}) + (h_{ff})(M_{ff}) \qquad \text{(B-1)}$$

$$= [(6{,}940 \text{ Btu/lb})(1{,}311 \text{ tons}) + (5{,}900 \text{ Btu/lb})(294 \text{ tons})](2{,}000 \text{ lb/ton})$$

$$= 2.167 \times 10^{10} \text{ Btu}$$

where: H_{sw} = energy derived from solid waste and supplied to HRI, Btu

h_{sw} = higher heating value of processed solid waste (Ref 8), Btu/lb

M_{12} = processed solid waste supplied to the HRI, tons

h_{ff} = higher heating value of floor-fed solid waste as received (Ref 12), Btu/lb

M_{ff} = floor-fed solid waste supplied to the HRI, tons

2. Energy derived from fuel oil:

$$H_{fo} = (h_{fo})(M_{20})(d_{fo}) \tag{B-2}$$

$$= (19{,}603 \text{ Btu/lb})(20{,}050 \text{ gal})(7.09 \text{ lb/gal})$$

$$= 2.787 \times 10^9$$

where: H_{fo} = energy derived from fuel oil and supplied to HRI, Btu

h_{fo} = higher heating value of fuel oil, 19,603 Btu/lb

M_{20} = fuel oil supplied to HRI, gal

d_{fo} = density of fuel oil, lb/gal

3. Energy derived from waste oil.

$$H_{wo} = (h_{wo})(M_{21})(d_{wo}) \tag{B-3}$$

$$= (19{,}673 \text{ Btu/lb})(0 \text{ gal})(6.86 \text{ lb/gal})$$

$$= 0 \text{ Btu (none used)}$$

where: H_{wo} = energy derived from waste oil and supplied to HRI, Btu

h_{wo} = higher heating value of waste oil, Btu/lb

M_{21} = waste oil supplied to HRI, gal

d_{wo} = density of waste oil, lb/gal

4. Energy derived from makeup water:

$$H_w = (h_w)(M_{17})(d_w) \tag{B-4}$$

$$= 0 \text{ Btu (none used)}$$

where: H_w = energy derived from makeup water, Btu

h_w = enthalphy of makeup water, Btu/lb

M_{17} = makeup water consumed, gal

d_w = makeup water density, lb/gal

5. Total energy derived from all sources supplied to the HRI:

$$H_{HRI} = H_{sw} + H_{fo} + H_{wo} + H_w \quad \text{(B-5)}$$

$$= 2.446 \times 10^{10} \text{ Btu}$$

6. Sum total of energy derived from auxiliary sources of energy:

$$H_{AUX} = H_{fo} + H_{wo} \quad \text{(B-6)}$$

$$= 2.787 \times 10^{9} \text{ Btu}$$

7. Percentage of total energy produced from auxiliary sources:

$$\frac{H_{AUX}}{H_{HRI}} = \frac{2.787 \times 10^{9}}{2.446 \times 10^{10}} = 11\% \quad \text{(B-7)}$$

8. Percentage of total energy produced from solid waste:

$$\frac{H_{HRI} - H_{AUX}}{H_{HRI}} = \frac{2.446 \times 10^{10} - 2.787 \times 10^{9}}{2.446 \times 10^{10}} = 89\% \quad \text{(B-8)}$$

FOSSIL FUEL OFFSETS

Fossil fuel offsets were calculated by subtracting the quantity of fossil fuels (fuel oil, electricity, and front-end loader diesel fuel) consumed by the HRI from the quantity of fossil fuels saved by the HRI. The fossil fuels saved are equivalent to the steam energy from solid waste divided by boiler efficiency. Equations B-9 through B-13 calculated the fossil fuels consumed or saved and the estimated fossil fuel offsets. The results from Equations A-1 to B-4 are used in Equations B-9 and B-12.

9. Fossil fuel energy - boiler:

$$FF_B = (H_{fo} + H_{wo} + H_{sw}) \times TE_{sw}/TE_B \quad \text{(B-9)}$$

$$= (2.787 \times 10^9 + 0 + 2.167 \times 10^{10}) \times 0.45/0.80$$

$$= 1.376 \times 10^{10} \text{ Btu of steam}$$

where: FF_B = fossil fuel energy used by the boiler, Btu

H_{fo} = energy derived from fuel oil, Btu

H_{wo} = energy derived from waste oil, Btu

H_{sw} = energy derived from solid waste, Btu

TE_{sw} = efficiency of solid waste energy conversion process

TE_B = efficiency of boiler energy conversion process

10. Heat derived from front-end loader diesel fuel:

$$H_{df} = (h_{df})(M_{22})(d_{df}) \quad \text{(B-10)}$$

$$= (19{,}603 \text{ Btu/lb})(970 \text{ gal})(7.09 \text{ lb/gal})$$

$$= 1.348 \times 10^8 \text{ Btu}$$

where: H_{df} = energy derived from front-end loader diesel fuel, Btu

h_{df} = heating value of diesel fuel, 19,603 Btu/lb

M_{22} = diesel fuel supplied to front-end loader, lb

d_{df} = density of diesel fuel, lb/gal

11. Energy equivalent of electrical power supplied to the HRI:

$$E_t = (e_t)(T_{kwh}) \quad \text{(B-11)}$$

$$= (11{,}600 \text{ Btu/kW-hr})(168{,}800 \text{ kW-hr})$$

$$= 1.958 \times 10^9 \text{ Btu}$$

where: E_t = electrical energy supplied to the HRI, Btu

e_t = conversion factor, 11,600 Btu/kW-hr

T_{kwh} = electricity supplied to the HRI, kW-hr

12. Fossil fuel energy - HRI:

$$\begin{aligned} FF_{HRI} &= H_{so} + H_{df} + E_t + H_w \qquad \text{(B-12)} \\ &= 2.787 \times 10^9 + 1.348 \times 10^8 + 1.958 \times 10^9 + 0 \\ &= 4.880 \times 10^9 \text{ Btu} \end{aligned}$$

where: FF_{HRI} = fossil fuel energy used by the HRI, Btu

H_{fo} = energy derived from fuel oils, Btu

H_{df} = energy derived from diesel fuel, Btu

E_t = energy derived from electricity, Btu

H_w = energy derived from makeup water, Btu

13. Fossil fuel offsets:

$$\begin{aligned} FFO &= \frac{(FF_B - FF_{HRI})}{CF_{FFO}} \qquad \text{(B-13)} \\ &= \frac{(1.376 \times 10^{10} - 4.880 \times 10^9 \text{ Btu})}{5.8 \times 10^6 \text{ Btu/BOE}} \\ &= 1{,}530 \text{ BOE or } 29.4 \text{ BOE/wk} \end{aligned}$$

where: FFO = fossil fuel offsets, BOE/wk

FF_B = fossil fuel energy used by the boiler, Btu

FF_{HRI} = fossil fuel energy used by the HRI, Btu

CF_{FFO} = conversion factor for fossil fuel offsets, 5.8×10^6 Btu/BOE

EXPECTED VALUES FOR MISSION RELIABILITY

Expected values for mission reliability were calculated based on Table 4 of the reliability analysis of the NAS Jacksonville HRI (Ref 6). Mission calculations were made using the predicted failure rates for each subsystem which was a part of the mission.

The failure rates and reliability for each subsystem are summarized in Table B-1. The mission reliabilities were obtained by multiplying together the reliability for each appropriate subsystem. The total failures were obtained by adding the appropriate subsystem failures. MTBF was calculated by dividing the mission time (6,240 hr/yr) by the total failures. These calculations are summarized in Table B-2.

Operational Parameters

The HRI accepted 1,871 tons and weighed but did not accept 5,577 tons, for a total of 7,448 tons. This represents 48 weeks of data over the 51-week study. Even though no data were recorded for 3 weeks, waste was generated during this time. Therefore, 48 weeks were used to determine waste generation. Fifty-one weeks were used for the other parameters because this value represented the HRI effort for the entire study period.

1. Solid waste generated:

$$\frac{7{,}448 \text{ tons}}{(5 \text{ days/wk}) \times 48 \text{ wk}} = 31.0 \text{ TPD}$$

2. Solid waste accepted:

$$\frac{1{,}871 \text{ tons}}{(5 \text{ days/wk}) \times 51 \text{ wk}} = 7.3 \text{ TPD}$$

3. Processing time:

$$\frac{673 \text{ hr}}{51 \text{ wk}} = 13.2 \text{ hr/wk}$$

(673 hours is the total processing time from Table 2.)

4. Incineration time:

$$\frac{3{,}592 \text{ hr}}{51 \text{ wk}} = 70.4 \text{ hr/wk}$$

(3,592 is the total incineration time from Table 2.)

5. Ash production:

Processed waste -- 82% of feed; 8% ash
Floor-fed waste -- 18% of feed; 15% ash

$$AP = 0.82 \times 0.08 + 0.18 \times 0.15$$

$$= 0.09 \text{ ton/ton}$$

Predicted Values

1. Waste energy content (Ref 9):

Floor fed: 6,534 Btu/lb (dry) x (1 - 9.72 (moisture)/100)

= 5,900 Btu/lb (as received)

Processed: 8,207 Btu/lb x (1 - 15.41/100) = 6,940 Btu/lb

2. Percentage energy supplied by solid waste:

Assume: 0.24 BOE/ton of waste (Ref 7)

6,940 Btu/lb of waste "as received"

$$\frac{6{,}940 \text{ Btu/lb} \times 2{,}000 \text{ lb/ton}}{5.8 \times 10^{6} \text{ Btu/BOE}} = 2.39 \text{ BOE/ton}$$

$$\frac{2.39}{2.39 + 0.24} = 0.91 \times 100 = 91\%$$

3. Fossil fuel offsets:

Assume: 25% of incoming waste was rejected (Ref 9)

45% thermal efficiency

35 kW-hr/ton of electricity consumed (Ref 7)

$$\begin{aligned} \text{FFO} &= [6{,}940 \text{ Btu/lb} \times 2{,}000 \text{ lb/ton} \times 0.45 - 35 \text{ kW-hr/ton} \\ &\quad \times 11{,}600 \text{ Btu/kW-hr}] \times (1 - 25/100) \times 200 \text{ tons/wk} \\ &\quad \div 5.8 \times 10^{6} \text{ Btu/BOE} \\ &= 151 \sim 150 \text{ BOE/wk} \end{aligned}$$

Table B-1. Subsystem Data for Reliability Calculations

Subsystem	Failure Rate (failure/10^6 hr)	Mission Time (hr/yr)	Total Failures[a] (no./yr)	MTBF[b] (hr)	Reliability[b] (%)
Receiving[c] (R)	0	--	0	--	1.0
Processing (P)	1,732	2,080	3.6	577	93.3
Storage (S)	280	6,240	1.7	3,571	96.6
Incineration[d] (I)	2,344	6,240	14.6	427	75.5
Oil Combustion[e] (OI)	500	6,240	3.1	2,000	94.2
Ash (A)	311	6,240	1.9	3,215	96.3
Boiler (B)	1,804	6,240	11.3	554	80.5

[a]Mission time/MTBF.

[b]Calculated from Appendix B equations.

[c]Assumed no failures occurred in the receiving subsystem; in other words, the waste was always able to reach the processing or incineration subsystems.

[d]This was the normal solid waste incineration function.

[e]This was the function when fuel oil was used to produce steam. The only incinerator equipment utilized were the burners (1/3-hp motor), thermocouples, and thermo switches for each incinerator.

Table B-2. Mission Reliabilities

Mission	Appropriate Subsystems[a]	Reliability[b] (%)	Total Failures[c] (no./yr)	MTBF[d] (hr)
1	R, P, S, I, A, B	53	34	184
2	R, P, S, I, A	66	22	284
3	R, I, A	73	17	367
4	R, I, A, B	59	28	223
5	OI, B	76	15	416

[a]These subsystems must be operational for the mission to be accomplished. See Table B-1 for the code.

[b]For example, Mission 1 reliability:
$1.0 \times 0.933 \times 0.966 \times 0.755 \times 0.963 \times 0.805 = 0.527 \times 100 = 53\%$

[c]For example, Mission 1 total failures:
$3.6 + 1.7 + 14.6 + 1.9 + 11.3 = 33.1$ or 34 failures/yr

[d]For example, Mission 1 mean time between failures:
6,240 hr/34 = 184 hr

Appendix C

PROCEDURES FOR COMPLETING

HEAT RECOVERY EQUIPMENT STATUS LOG

AND

CONSUMABLES AND RUN TIME LOG

I. EQUIPMENT STATUS LOG

The following specific instructions were followed for completing the Equipment Status Log. The number in parentheses refers to the identical block/column on the log. As a minimum, one entry per working shift was logged regarding the operating status of the HRI, even if there were no changes in status.

(1) Installation

Enter the station location and system name. Example: NAS JAX HRI

(2) Beginning Date

Enter the year, month, and day using a two-digit number, for the initial day being reported on each sheet. Notice that more than one day's events can be recorded on a single sheet. Example: 82/01/22.

(3) Page of Pages

Enter the number of each page for the entire work week starting with number 1 on Monday morning.

(4) Date

Record the day of the month that corresponds to any subsequent entries. At least one entry per shift is required.

(5) Time

Record the time at the beginning of every day (usually 0001) using military time (1630 instead of 4:30 p.m.). Record the time of any change in equipment status. Record the beginning and ending time of other events (i.e., maintenance actions and other downtimes).

(6) Code

Enter the equipment status category code at the beginning of every day (0001 hours). Enter all changes in equipment status. Identify what equipment status changed with the equipment codes. The status category and equipment definition list will

aid in determining the correct status code. See Figures C-1 and C-2 examples.

(7) <u>MHRS</u>

Enter the maintenance man-hours required to perform the maintenance actions. If, for example, 2 hours of preventive maintenance man-hours and 8 hours of correction maintenance man-hours are performed simultaneously, then list those man-hours spent in preventive maintenance first. Example: 2/8.

(8) <u>Explanation</u>

All information that will aid the technical analysis should be recorded in the remarks section. Use as many lines as needed to explain actions taken. Entries shall be in accordance with the following guidelines:

1. Entries are required for any of the following reasons:

   a. System, subsystem, equipment, or component turn on or off.

   b. Equipment failure.

   c. Restoration of equipment to full capacity.

   d. Preventive or corrective maintenance action.

   e. All part replacement actions.

   f. Outside assistance required, requested, or received from other than HRI assigned personnel.

2. The description should be brief but answer the following questions:

   a. What is the operational status of the equipment?

   b. What has occurred? Failure, maintenance, test?

   c. What is being done to change status?

   Entries shall answer all of the above questions.

   Example: "Ash conveyor inoperative - troubleshooting motor and inspecting belt."

(9) <u>For Analyst Only</u>

Do not write in this space. This is to be used by data analyst only.

(10) Supervisor

Supervisor responsible for data collection should initial each sheet as the sheet is completed, verify that all necessary entries have been made and each event has been adequately described.

II. CODES FOR EQUIPMENT STATUS LOG

The following codes were used in conjunction with the entry made in the remarks column. An "R" next to any code indicated performance of routine (preventive) maintenance during this period. Start and completion times of routine maintenance were indicated in appropriate column of equipment log.

CODE	DEFINITION
1	UP-Operating. Equipment was energized and was being operated at full or reduced capability. Certain routine maintenance actions were reported in this or other UP code.
2	UP-Secured. Equipment was idle; not energized but capable of being operated. Includes time (shutdown) due to reasons other than routine maintenance or failure. Examples were lack of solid waste or fuels, holidays, and weekends.
3	DOWN-Corrective Maintenance. Equipment was idle and not fully operable using normal operating procedures because corrective maintenance was being performed. That is, some equipment was undergoing repair, part replacement, alignment, or adjustment in order to correct a failed or out of tolerance condition.
4	DOWN-Awaiting Spares. Equipment was not fully operable using normal operating procedures because spare parts were needed which were not available within the facility. The equipment could not be restored to an operable status until parts were procured.
5	DOWN-Awaiting Outside Assistance. The equipment was not capable of operating at full or reduced capability on demand and required assistance from other than HRI personnel to restore to operable status.
6	DOWN-Administrative Delay. The equipment was not capable of operating at full or reduced capability on demand. This included time for lunch, dinner, holidays, shift changes, etc.
7	DOWN-Preventive Maintenance. Planned or routine maintenance was being performed which rendered the equipment inoperable until completion.

III. CODES FOR SYSTEMS AND COMPONENTS

The following codes were used to show system status.

CODE	DEFINITION
A	Ash handling subsystem - included motor and conveyor.
B	Boiler subsystem - included boiler, water and steam lines, makeup water equipment, and blowdown components.
H	HRI - included all equipment.
I	Incinerator subsystem - included incinerator, controls, feed hoppers, stokers, and burners.
P	Processing subsystem - included flail mill, shredder, magnetic separator, trommel, and associated feed/discharge conveyors.
R	Receiving subsystem - included tipping floor and front-end loader.
S	Storage subsystem - included storage bin, screw augers, and feed conveyors.
T	Heat transfer subsystem - included B and I.

Figures C-1 and C-2 provide an example of completed equipment status logs representing an entire week. This sample scenario began with the start of a work week (Monday morning).

IV. CONSUMABLES AND RUN TIME LOG SHEET

The following specific instructions were followed for completing the Consumables and Run Time Log Sheet (Figure C-3).

It was the responsibility of the chief supervisor to supply all information. The form was completed on a weekly basis at the completion of each work week. All weights recorded represented the weekly totals.

ITEM	DEFINITION
1	Week Ending Date. Record the date in which the form is completed.
2	Sheet No.. Number each Log Sheet (week) in the sequence used. This will be used as a reference number for each sheet.
3	Solid Waste Received (tons). Record the total (in tons) weight of solid waste dumped on the tipping floor during the work week. Note: Since all scale values reported on this form represent weekly totals only, a separate daily log may be necessary.
4	Solid Waste Not Accepted (tons). Record the estimated weight of solid waste which could not be received due to the limited capacity of the tipping floor. If waste could not be accepted for other reasons please discuss under item 18.
5	Rejected by Hand (pounds). Record the weight (pounds) of the solid waste picked out by hand to be sent to landfill.
6	Trommel and Magnet Rejects (pounds). Record the weight (pounds) of the solid waste removed by undersize waste conveyor from trommel screen and magnetic separator to be sent to landfill.
7	Rejected by Dust Filter (pounds). Record the weight (pounds) of the solid waste removed by the dust collector as fly ash to be sent to landfill.
8	Wet Ash Removed (pounds). Record the weight (pounds) of the wet ash removed from the quench trough by the ash conveyor.
9	Electrical Energy (kW-hr). Record the amount of electrical energy (in kilowatt hours) used by the HRI during the week.
10	Boiler Feedwater (gallons). Record the amount of feedwater (in gallons) supplied to the boiler(s) during this week.

11 Blowdown (gallons). Record the amount of blowdown (in gallons) recovered from the boiler(s) during the week.

12 Flail Mill Feed Conveyor (run time). Record the meter reading at the end of each week.

13 Shredder Feed Conveyor (run time). Record the meter reading at the end of each week.

14 Storage Bin Feed Conveyor (run time). Record the meter reading at the end of each week.

15 Ash Conveyor (run time). Record the meter reading at the end of each week.

16 Incinerator Blower Number 1 (run time). Record the meter reading at the end of each week.

17 Incinerator Blower Number 2 (run time). Record the meter reading at the end of each week.

18 Incinerator Blower Number 3 (run time). Record the meter reading at the end of each week.

19 Induced Draft Fan Number 1 (run time). Record the meter reading at the end of each week.

20 Induced Draft Fan Number 2 (run time). Record the meter reading at the end of each week.

21 Induced Draft Fan Number 3 (run time). Record the meter reading at the end of each week.

22 Boiler Number 1 Steam (pounds). Record the meter reading at the end of each week.

23 Boiler Number 2 Steam (pounds). Record the meter reading at the end of each week.

24 Boiler Number 3 Steam (pounds). Record the meter reading at the end of each week.

25 Diesel Fuel (gallons). Record the amount of diesel fuel (in gallons) supplied to the front-end loader. Since this is not metered, another sheet may be required for totaling.

26 Hydraulic Oil (gallons). Record the amount of hydraulic oil (in gallons) used by the HRI. This value should represent oil changes and hydraulic leakages.

27 No. 2 Fuel Oil (gallons). Record the amount of No. 2 fuel oil (in gallons) consumed by the HRI during the week.

28 Waste Oil (gallons). Record the amount of waste oil (in gallons) consumed by the HRI during the week.

29 Repair Parts (specify WR No.). Record the work request (WR) numbers of any parts used to repair and maintain the HRI during the week.

30 Comments. Use this space to discuss any pertinent information. Include also additional information requested by items 4 and 9. Use back of form if necessary.

31 Initial. Supervisor to initial each logsheet once completed.

HRI EQUIPMENT STATUS LOG

1. INSTALLATION	2. BEGINNING DATE YEAR MONTH DAY	3. PAGE OF PAGES
NAS JAX	8 0 0 9 2 9	1

4. DATE	5. TIME	6. CODE	7. MHRS	8. EXPLANATIONS
29	0730	T1R		HRI start up. Began cleaning trommel screen--Routine Mainte-
				nance. HRI burning waste that was left in storage from last
			2	week in Incinerator #2.
29	0830	H1		Completed routine maintenance. Began processing waste.
29	1630	P2		Shut down processing. Continue to burn from storage bin in
				Incinerator #2.
30	0000	T1		HRI operating without problems.
	0800	A7		Begin routine maintenance. During this time we replaced the
				belt on the ash conveyor drive motor due to excessive wear,
				cleaned primary and secondary chambers for incinerators #1 and
			6	#3. #2 still burning on fuel oil.
	1230	H1		Routine Maintenance completed. Began processing solid waste.
	1630	P2		Secure processing for the day. Continue burning in incinera-
				tor #2 and start burning in #3.
01	0000	H1		HRI operating trouble free. Began processing waste.
	0700	T3		Ash conveyor won't work. Troubleshooting. Stopped burning.
	0830	T3	3	Seems to be problem in drive motor.
		T5		Called for help at this time. Still processing waste.
	1330	T3	1.5	Electrician arrives—begin troubleshooting
	1500	T3		Drive motor bearings are shot! Placed order for entire new
		T4		motor.
	1630	H4R		Stopped processing waste. Shift change. Still waiting for
				part (motor). Should receive it tomorrow afternoon. At
				present, we are not incinerating due to ash conveyor problem.
				Sweeping facility and cleaning incinerator #2 slag buildup.
				Noticed an exceptional amount of slag has accumulated during
				the past few days. Probably due to excess air entering through
			3	feed door, high primary furnace temperature.
02	0000	H4		Ash conveyor still down. All equipment idle.
	1630	H4		End of day and still no motor. Base supply office says that
				we will definitely receive one by tomorrow. No regular
				scheduled maintenance performed.

9. FOR ANALYST ONLY	10. SUPERVISOR

Sample

Figure C-1. Completed equipment status log.

HRI EQUIPMENT STATUS LOG

1. INSTALLATION	2. BEGINNING DATE (YEAR MONTH DAY)	3. PAGE ___ OF PAGES
NAS JAX	80 10 03	2

4. DATE	5. TIME	6. CODE	7. MHRS	8. EXPLANATIONS
03	0000	H4R		Performing maintenance checks described in operation manual,
				page 10. Required changing oil breather. Noticed slight oil
				leak from reducer.
	1100	H4	2	Completed maintenance checks.
	1300	H3		Received drive motor! Installing.
	1420	H3	1.5	Completed installation--testing ash conveyor. All OK.
	1430	H2		Secured all equipment since today is Friday. Will resume
				incineration on Monday.
04	0000	H2		Secured for weekend.
05	0000	H2		Secured
06	0000	H2		Secured
	0800	H1		Began processing and incinerating in #2 and #3.
	0930	H1	0	Hopper ram stuck on #2. Unstuck itself after 3 attempts.
				No cause found.
	1500	T1		Stopped processing. Continued burning using #1 now.
	2100	B3		Boiler feed pump inoperable. Troubleshooting.
	2300	B6		Could not find problem. Shut down steam production until
				morning shift comes in. Continued incineration.
07	0000	B6		Boiler feed still inoperable. Continue incineration.
	0730	B3R		Began working on boiler feed problem while couple guys
				perform routine maintenance on boilers #1, 2 and 3.
	0930	H1	6/2	Completed both PM and CM. Boiler feed problem resolved.
				Cause was inoperable shut off valve. Resumed complete
				operation.

9. FOR ANALYST ONLY	10. SUPERVISOR

Figure C-2. Completed equipment status log.

HRI CONSUMABLES and RUN TIME LOG

1. WEEK ENDING DATE ________ (Month/Day/Year) 2. SHEET NO. ________

3. SOLID WASTE RECEIVED (TONS)	4. SOLID WASTE NOT ACCEPTED (TONS)	5. REJECTED BY HAND (LBS)	6. TROMMEL AND MAGNET REJECTS (LBS)	7. REJECTED BY DUST FILTER (LBS)
8. WET ASH REMOVED (LBS)	9. ELECTRICAL ENERGY (KWH)	10. BOILER FEED WATER (GALLONS)	11. BLOWDOWN (GALLONS)	12. FLAIL MILL FEED CONVEYOR (RUN TIME)
13. SHREDDER FEED CONVEYOR (RUN TIME)	14. STORAGE BIN FEED CONVEYOR (RUN TIME)	15. ASH CONVEYOR (RUN TIME)	16. INCINERATOR BLOWER 1 (RUN TIME)	17. INCINERATOR BLOWER 2 (RUN TIME)
18. INCINERATOR BLOWER 3 (RUN TIME)	19. INDUCED DRAFT FAN 1 (RUN TIME)	20. INDUCED DRAFT FAN 2 (RUN TIME)	21. INDUCED DRAFT FAN 3 (RUN TIME)	22. BOILER 1 STEAM (LBS)
23. BOILER 2 STEAM (LBS)	24. BOILER 3 STEAM (LBS)	Non-Metered Items		
		25. DIESEL FUEL (to front-end loader): ________ Gallons 26. HYDRAULIC OIL used: ________ Gallons 27. No. 2 FUEL OIL used: ________ Gallons 28. WASTE OIL used: ________ Gallons		

29. REPAIR PARTS Specify WR No.):

30. COMMENTS:

31. INITIAL ________

Figure C-3. Consumables and run time log.

DISTRIBUTION LIST

AFB Hq Space Com Deeq (P. Montoya) Peterson AFB, CO; 82ABG DEMC, Williams AZ; ABG DEE (F. Nethers), Goodfellow AFB TX; AFESC TST, Tyndall FL; AUL LSE 63-465, Maxwell AL; HQ MAC DEEE, Scott, Il; HQ Tactical Air Cmd DEMM (Schmidt) Langley, VA; SAMSO MNND, Norton AFB CA; Samso Dec (Sauer) Vandenburg, CA; Stinfo Library, Offutt NE

AFESC DEB, Tyndall, FL

ARMY ARRADCOM, Dover, NJ; BMDSC-RE (H. McClellan) Huntsville AL; Contracts - Facs Engr Directorate, Fort Ord, CA; DAEN-CWE-M, Washington DC; DAEN-MPE-D Washington DC; DAEN-MPU, Washington DC; ERADCOM Tech Supp Dir. (DELSD-L) Ft. Monmouth, NJ; Engr District (Memphis) Library, Memphis TN; HQDA (DAEN-FEE-A); Natick R&D Command (Kwoh Hu) Natick MA; Tech. Ref. Div., Fort Huachuca, AZ

ARMY - CERL Library, Champaign IL

ARMY CORPS OF ENGINEERS MRD-Eng. Div., Omaha NE; Seattle Dist. Library, Seattle WA

ARMY CRREL G. Phetteplace Hanover, NH

ARMY ENG DIV HNDED-CS, Huntsville AL; HNDED-FD, Huntsville, AL

ARMY ENGR DIST. Library, Portland OR

ARMY ENVIRON. HYGIENE AGCY Dir Env Qual Aberdeen Proving Ground MD; HSE-EW Water Qual Eng Div Aberdeen Prov Grnd MD; HSE-RP-HG Pest Coord. Arberdeen Proving Ground, MD; Librarian, Aberdeen Proving Ground MD

ARMY MATERIALS & MECHANICS RESEARCH CENTER Dr. Lenoe, Watertown MA

ARMY MISSILE R&D CMD SCI Info Cen (DOC) Redstone Arsenal, AL

ARMY-MERADCOM CFLO Engr Fort Belvoir VA; DRDME-WC Ft Belvoir VA

ADMINSUPU PWO, BAHRIAN

ASO PWD (ENS M W Davis), Phildadelphia, PA

BUMED Security Offr, Washington DC

BUREAU OF RECLAMATION Code 1512 (C. Selander) Denver CO

CINCLANT CIV ENGR SUPP PLANS OFFR NORFOLK, VA

CINCPAC Fac Engrng Div (J44) Makalapa, HI

CINCUSNAVEUR Fleet Civil Engr, London, England

COMNAVRESFOR Code 473, New Orleans, LA

CNM Code MAT-04, Washington, DC; Code MAT-08E, Washington, DC; NMAT - 044, Washington DC

CNO Code NOP-964, Washington DC; Code OP 987 Washington DC; Code OP-413 Wash, DC; Code OPNAV 09B24 (H); OP-098, Washington, DC; OP987J, Washington, DC

COMFAIRMED SCE, Code N55, Naples IT

COMFLEACT, OKINAWA PWO, Kadena, Okinawa; SCE, Yokosuka Japan

COMNAVMARIANAS Code N4, Guam

COMNAVSUPPFORANTARCTICA PWO Det Christchurch

COMOCEANSYSLANT PW-FAC MGMNT Off Norfolk, VA

COMOCEANSYSPAC SCE, Pearl Harbor HI

COMSUBDEVGRUONE Operations Offr, San Diego, CA

DEFFUELSUPPCEN DFSC-OWE (Term Engrng) Alexandria, VA; DFSC-OWE, Alexandria VA

DOD Staff Spec. Chem. Tech. Washington DC

DOE Div Ocean Energy Sys Cons/Solar Energy Wash DC; INEL Tech. Lib. (Reports Section), Idaho Falls, ID

DTIC Defense Technical Info Ctr/Alexandria, VA

DTNSRDC Anna Lab (Code 4120) Annapolis MD

DTNSRDC Code 4111 (R. Gierich), Bethesda MD; Code 42, Bethesda MD

DTNSRDC Code 522 (Library), Annapolis MD

ENVIRONMENTAL PROTECTION AGENCY Reg. III Library, Philadelphia PA; Reg. VIII, 8M-ASL, Denver CO

FLTCOMBATTRACENLANT PWO, Virginia Bch VA

GIDEP OIC, Corona, CA

GSA Assist Comm Des & Cnst (FAIA) D R Dibner Washington, DC ; Off of Des & Const-PCDP (D Eakin) Washington, DC

KWAJALEIN MISRAN BMDSC-RKL-C

LIBRARY OF CONGRESS Washington, DC (Sciences & Tech Div)

MARINE CORPS BASE Code 4.01 (Asst Chief Engr) Camp Pendleton, CA; Code 406, Camp Lejeune, NC; M & R Division, Camp Lejeune NC; Maint Off Camp Pendleton, CA; PWD - Maint. Control Div. Camp Butler, Kawasaki, Japan; PWO Camp Lejeune NC; PWO, Camp Pendleton CA; PWO, Camp S. D. Butler, Kawasaki Japan

MARINE CORPS HQS Code LFF-2, Washington DC

MCAS Facil. Engr. Div. Cherry Point NC; CO, Kaneohe Bay HI; Code S4, Quantico VA; Facs Maint Dept - Operations Div. Cherry Point; PWD - Utilities Div, Iwakuni, Japan; PWO, Iwakuni, Japan; PWO, Yuma AZ

MCDEC M&L Div Quantico VA; NSAP REP, Quantico VA
MCLB B520, Barstow CA; Maintenance Officer, Barstow, CA; PWO, Barstow CA
MCRD SCE, San Diego CA
MILITARY SEALIFT COMMAND Washington DC
NAF PWD - Engr Div, Atsugi, Japan; PWO, Atsugi Japan
NALF OINC, San Diego, CA
NARF Code 100, Cherry Point, NC; Code 612, Jax, FL; Code 640, Pensacola FL; SCE Norfolk, VA
NAS CO, Guantanamo Bay Cuba; Security Officer, Kingsville TX; Code 114, Alameda CA; Code 183 (Fac Plan BR MGR); Code 183, Jacksonville FL; Code 187, Jacksonville FL; Code 18700, Brunswick ME; Code 18U (ENS P.J. Hickey), Corpus Christi TX; Code 70, Atlanta, Marietta GA; Code 8E, Patuxent Riv., MD; Dir of Engrng, PWD, Corpus Christi, TX
NAVAIRSYSCOM PWD Code 8P (Grover) Patuxent River, MD
NAS Lakehurst, NJ; Lead. Chief. Petty Offr. PW/Self Help Div, Beeville TX; PW (J. Maguire), Corpus Christi TX; PWD - Engr Div Dir, Millington, TN; PWD - Engr Div, Oak Harbor, WA; PWD - Maint. Control Dir., Millington, TN; PWD Maint. Cont. Dir., Fallon NV; PWD Maint. Div., New Orleans, Belle Chasse LA; PWD, Maintenance Control Dir., Bermuda; PWD, Willow Grove PA; PWO (Code 18.2), Bermuda; PWO Belle Chasse, LA; PWO Chase Field Beeville, TX; PWO Key West FL; PWO Lakehurst, NJ; PWO Patuxent River MD; PWO Sigonella Sicily; PWO Whiting Fld, Milton FL; PWO, Cecil Field FL; PWO, Dallas TX; PWO, Glenview IL; PWO, Kingsville TX; PWO, Millington TN; PWO, Miramar, San Diego CA; PWO, Oceana, Virginia Bch VA; PWO, So. Weymouth MA; SCE Norfolk, VA; SCE, Barbers Point HI
NATL RESEARCH COUNCIL Naval Studies Board, Washington DC
NATNAVMEDCEN Code 47 Med. R&D Cmd, Bethesda MD
NAVACT PWO, London UK
NAVACTDET PWO, Holy Lock UK
NAVAEROSPREGMEDCEN SCE, Pensacola FL
NAVAIRDEVCEN PWD, Engr Div Mgr, Warminster, PA
NAVAIRPROPTESTCEN CO, Trenton, NJ
NAVAIRTESTCEN PATUXENT RIVER PWD (F. McGrath), Patuxent Riv.,MD
NAVAUDSVCHQ Director, Falls Church VA
NAVAVIONICFAC PW Div Indianapolis, IN; PWD Deputy Dir. D/701, Indianapolis, IN
NAVCOASTSYSCEN CO, Panama City FL; Code 423 Panama City, FL; Code 715 (J Quirk) Panama City, FL; Library Panama City, FL; PWO Panama City, FL
NAVCOMMAREAMSTRSTA Maint Control Div., Wahiawa, HI; PWO, Norfolk VA; SCE Unit 1 Naples Italy; SCE, Guam; SCE, Wahiawa HI; Sec Offr, Wahiawa, HI
NAVCOMMSTA Code 401 Nea Makri, Greece; PWD - Maint Control Div, Diego Garcia Is.; PWO, Exmouth, Australia; SCE, Balboa, CZ
NAVCONSTRACEN Code 00U15, Port Hueneme CA
NAVEDTRAPRODEVCEN Technical Library, Pensacola, FL
NAVEDUTRACEN Engr Dept (Code 42) Newport, RI
NAVENVIRHLTHCEN CO, NAVSTA Norfolk, VA
NAVEODTECHCEN Code 605, Indian Head MD
NAVFAC PWO, Brawdy Wales UK; PWO, Centerville Bch, Ferndale CA; PWO, Point Sur, Big Sur CA
NAVFACENGCOM Alexandria, VA; Code 03 Alexandria, VA; Code 03T (Essoglou) Alexandria, VA; Code 04T1B (Bloom), Alexandria, VA; Code 04A1 Alexandria, VA; Code 04B3 Alexandria, VA; Code 051A Alexandria, VA; Code 09M54, Tech Lib, Alexandria, VA; Code 100, Alexandria, VA; Code 1113, Alexandria, VA; Code 082, Alexandria, VA
NAVFACENGCOM - CHES DIV. Code 101 Wash, DC; Code 403 Washington DC; Code 405 Wash, DC; FPO-1 Washington, DC; Library, Washington, D.C.
NAVFACENGCOM - LANT DIV. Code 111, Norfolk, VA; Code 403, Norfolk, VA; Code 405 Civil Engr BR Norfolk VA; Eur. BR Deputy Dir, Naples Italy; Library, Norfolk, VA; Code 1112, Norfolk, VA
NAVFACENGCOM - NORTH DIV. (Boretsky) Philadelphia, PA; CO; Code 09 Philadelphia, PA; Code 04AL, Philadelphia PA; Code 09P Philadelphia PA; Code 11, Phila PA; Code 111 Philadelphia, PA; Code 114 (A. Rhoads); ROICC, Contracts, Crane IN
NAVFACENGCOM - PAC DIV. (Kyi) Code 101, Pearl Harbor, HI; CODE 09P PEARL HARBOR HI; Code 402, RDT&E, Pearl Harbor HI; Library, Pearl Harbor, HI
NAVFACENGCOM - SOUTH DIV. Code 403, Gaddy, Charleston, SC; Code 406 Charleston, SC; Code 1112, Charleston, SC; Library, Charleston, SC
NAVFACENGCOM - WEST DIV. AROICC, Contracts, Twentynine Palms CA; Code 04B San Bruno, CA; Code 101.6 San Bruno, CA; Code 114C, San Diego CA; Code 405 San Bruno, CA; Library, San Bruno, CA; 09P/20 San Bruno, CA; RDT&ELO San Bruno, CA; Security Offr, San Diego CA

NAVFACENGCOM CONTRACTS AROICC, NAVSTA Brooklyn, NY; AROICC, Quantico, VA; Contracts, AROICC, Lemoore CA; Dir. Eng. Div., Exmouth, Australia; Dir. of Constr. Tupman, CA; Eng Div dir, Southwest Pac, Manila, PI; OICC, Southwest Pac, Manila, PI; OICC-ROICC, NAS Oceana, Virginia Beach, VA; OICC ROICC, Balboa Panama Canal; OICC ROICC, Norfolk, VA; ROICC AF Guam; ROICC Code 495 Portsmouth VA; ROICC Key West FL; ROICC, Keflavik, Iceland; ROICC, NAS, Corpus Christi, TX; ROICC, Pacific, San Bruno CA; ROICC, Point Mugu, CA; ROICC, Yap; ROICC-OICC-SPA, Norfolk, VA
NAVFORCARIB Commander (N42), Puerto Rico
NAVHOSP CO, Millington, TN
NAVMAG SCE, Subic Bay, R.P.
NAVOCEANO Library Bay St. Louis, MS
NAVOCEANSYSCEN Code 4473B (Tech Lib) San Diego, CA; Code 523 (Hurley), San Diego, CA; Code 6700, San Diego, CA; Code 811 San Diego, CA
NAVORDSTA PWO, Louisville KY
NAVPETOFF Code 30, Alexandria VA
NAVPETRES Director, Washington DC
NAVPGSCOL E. Thornton, Monterey CA; PWO Monterey CA
NAVPHIBASE CO, ACB 2 Norfolk, VA
NAVFACENGCOM - LANT DIV. Code 401D, Norfolk, VA
NAVPHIBASE PWO Norfolk, VA; SCE Coronado, SD,CA
NAVRADRECFAC PWO, Kami Seya Japan
NAVREGMEDCEN Code 29, Env. Health Serv. (Al Bryson) San Diego, CA; PWD - Engr Div, Camp Lejeune, NC; PWO, Camp Lejeune, NC
NAVREGMEDCEN PWO, Okinawa, Japan
NAVREGMEDCEN SCE; SCE San Diego, CA; SCE, Camp Pendleton CA; SCE, Guam; SCE, Newport, RI; SCE, Oakland CA
NAVREGMEDCEN SCE, Yokosuka, Japan
NAVSCOLCECOFF C35 Port Hueneme, CA; CO, Code C44A Port Hueneme, CA
NAVSCSOL PWO, Athens GA
NAVSEASYSCOM SEA 04E (L Kess) Washington, DC
NAVSECGRUACT PWO Winter Harbor ME; PWO, Adak AK; PWO, Edzell Scotland; PWO, Puerto Rico; PWO, Torri Sta, Okinawa
NAVSECGRUCOM Code G43, Washington DC
NAVSECSTA PWD - Engr Div, Wash., DC; Security Offr, Washington DC
NAVSHIPREPFAC SCE, Yokosuka Japan
NAVSHIPYD Bremerton, WA (Carr Inlet Acoustic Range); Code 202.4, Long Beach CA; Code 202.5 (Library) Puget Sound, Bremerton WA; Code 380, Portsmouth, VA; Code 382.3, Pearl Harbor, HI; Code 400, Puget Sound; Code 410, Mare Is., Vallejo CA; Code 440 Portsmouth NH; Code 440, Norfolk; Code 440, Puget Sound, Bremerton WA; Code 453 (Util. Supr), Vallejo CA; Code 457 (Maint. Supr.) Mare Island, Vallejo CA; L.D. Vivian; Library, Portsmouth NH; PW Dept, Long Beach, CA; PWD (Code 420) Dir Portsmouth, VA; PWD (Code 450-HD) Portsmouth, VA; PWD (Code 453-HD) SHPO 03, Portsmouth, VA; PWD - Utilities Supt, Code 903, Long Beach, CA; PWO Charleston Naval Shipyard, Charleston SC; PWO, Bremerton, WA; PWO, Mare Is.; PWO, Puget Sound; SCE, Pearl Harbor HI; Tech Library, Vallejo, CA
NAVSTA Adak, AK; CO Roosevelt Roads P.R. Puerto Rico; CO, Brooklyn NY; Code 16P, Keflavik, Iceland; Code 4, 12 Marine Corps Dist, Treasure Is., San Francisco CA; Dir Engr Div, PWD, Mayport FL; Engr. Dir., Rota Spain; Long Beach, CA; PWD (LTJG.P.M. Motolenich), Puerto Rico; PWD - Engr Dept, Adak, AK; PWD - Engr Div, Midway Is.; PWO, Keflavik Iceland; PWO, Mayport FL; SCE, Guam, Marianas; SCE, Pearl Harbor HI; SCE, San Diego CA
NAVSUPPFAC PWD - Maint. Control Div, Thurmont, MD
NAVSUPPO Security Offr, Sardinia
NAVSURFWPNCEN PWO, Dahlgren VA; PWO, White Oak, Silver Spring, MD
NAVTECHTRACEN SCE, Pensacola FL
NAVTELCOMMCOM Code 53, Washington, DC
NAVWARCOL Dir. of Facil., Newport RI
NAVWPNCEN Code 24 (Dir Safe & Sec) China Lake, CA; Code 2636 China Lake; PWO (Code 266) China Lake, CA; ROICC (Code 702), China Lake CA
NAVWPNSTA (Clebak) Colts Neck, NJ; Code 092, Colts Neck NJ; Code 092, Concord CA; Code 092A, Seal Beach, CA; Engrng Div, PWD Yorktown, VA; Maint. Control Dir., Yorktown VA
NAVWPNSTA PW Office Yorktown, VA
NAVWPNSTA PWD - Maint Control Div, Charleston, SC; PWD - Maint. Control Div., Concord, CA; PWD - Supr Gen Engr, Seal Beach, CA; PWO Colts Neck, NJ; PWO, Charleston, SC; PWO, Seal Beach CA
NAVWPNSUPPCEN Code 09 Crane IN
NCTC Const. Elec. School, Port Hueneme, CA

NCBC Code 10 Davisville, RI; Code 15, Port Hueneme CA; Code 155, Port Hueneme CA; Code 156, Port Hueneme, CA; Code 25111 Port Hueneme, CA; Code 430 (PW Engrng) Gulfport, MS; Code 470.2, Gulfport, MS; Library, Davisville, RI; NEESA Code 252 (P Winters) Port Hueneme, CA; PWO (Code 80) Port Hueneme, CA; PWO, Davisville RI; PWO, Gulfport, MS; Technical Library, Gulfport, MS
NCR 20, Commander
NMCB FIVE, Operations Dept; THREE, Operations Off.
NOAA Library Rockville, MD
NORDA Code 410 Bay St. Louis, MS
NRL Code 5800 Washington, DC
NSC CO, Biomedical Rsch Lab, Oakland CA; Code 09A Security Offr, Norfolk, VA; Code 54.1 Norfolk, VA; Code 700 Norfolk, VA; SCE Norfolk, VA; SCE, Charleston, SC
NSD SCE, Subic Bay, R.P.
NSWSES Code 0150 Port Hueneme, CA
NTC OICC, CBU-401, Great Lakes IL; SCE, San Diego CA
NUCLEAR REGULATORY COMMISSION T.C. Johnson, Washington, DC
NUSC DET Code 5202 (S. Schady) New London, CT; Code EA123 (R.S. Munn), New London CT; Code SB 331 (Brown), Newport RI
OFFICE SECRETARY OF DEFENSE OASD (MRA&L) Dir. of Energy, Pentagon, Washington, DC
ONR Code 221, Arlington VA; Code 700F Arlington VA
PACMISRANFAC HI Area Bkg Sands, PWO Kekaha, Kauai, HI
PHIBCB 1 P&E, San Diego, CA
PWC ACE Office Norfolk, VA; CO, (Code 10), Oakland, CA; Code 10, Great Lakes, IL; Code 105 Oakland, CA; Code 110, Great Lakes, IL; Code 110, Oakland, CA; Code 121.1, Oakland, CA; Code 128, Guam; Code 154 (Library), Great Lakes, IL; Code 200, Great Lakes IL; Code 30V, Norfolk, VA; Code 400, Great Lakes, IL; Code 400, Pearl Harbor, HI; Code 400, San Diego, CA; Code 420, Great Lakes, IL; Code 420, Oakland, CA; Code 424, Norfolk, VA; Code 500 Norfolk, VA; Code 500, Great Lakes, IL; Code 500, Oakland, CA; Code 505A Oakland, CA; Code 600, Great Lakes, IL; Code 610, San Diego Ca; Code 700, Great Lakes, IL; Code 700, San Diego, CA; Code 800, San Diego, CA; Library, Code 120C, San Diego, CA; Library, Guam; Library, Norfolk, VA; Library, Pearl Harbor, HI; Library, Pensacola, FL; Library, Subic Bay, R.P.; Library, Yokosuka JA; Production Officer, Norfolk, VA; Util Dept (R Pascua) Pearl Harbor, HI; Utilities Officer, Guam
SPCC PWO (Code 120) Mechanicsburg PA
SUPANX PWO, Williamsburg VA
TVA Solar Group, Arnold, Knoxville, TN
US GEOLOGICAL SURVEY Off. Marine Geology, Piteleki, Reston VA
USAF REGIONAL HOSPITAL Fairchild AFB, WA
USCG G-MMT-4/82 (J Spencer); Library Hqs Washington, DC
USCG R&D CENTER Library New London, CT
USDA Ext Service (T. Maher) Washington, DC; Forest Products Lab, Madison WI; Forest Service Reg 3 (R. Brown) Albuquerque, NM; Forest Service, Bowers, Atlanta, GA; Forest Service, San Dimas, CA
USNA Ch. Mech. Engr. Dept Annapolis MD; ENGRNG Div, PWD, Annapolis MD; Energy-Environ Study Grp, Annapolis, MD; Mech. Engr. Dept. (C. Wu), Annapolis MD; PWO Annapolis MD
USS FULTON WPNS Rep. Offr (W-3) New York, NY
USS JASON Repair Officer, San Francisco, CA
BROOKHAVEN NATL LAB M. Steinberg, Upton NY
GEORGIA INSTITUTE OF TECHNOLOGY (LT R. Johnson) Atlanta, GA

INSTRUCTIONS

The Naval Civil Engineering Laboratory has revised its primary distribution lists. The bottom of the mailing label has several numbers listed. These numbers correspond to numbers assigned to the list of Subject Categories. Numbers on the label corresponding to those on the list indicate the subject category and type of documents you are presently receiving. If you are satisfied, throw this card away (or file it for later reference).

If you want to change what you are presently receiving:

- Delete – mark off number on bottom of label.
- Add – circle number on list.
- Remove my name from all your lists – check box on list.
- Change my address – line out incorrect line and write in correction (ATTACH MAILING LABEL).
- Number of copies should be entered after the title of the subject categories you select.

Fold on line below and drop in the mail.

Note: Numbers on label but not listed on questionnaire are for NCEL use only, please ignore them.

Fold on line and staple

DEPARTMENT OF THE NAVY

NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300
1 IND-NCEL.2700/4 (REV. 12-73)
0930-LL-L70-0044

POSTAGE AND FEES PAID
DEPARTMENT OF THE NAVY
DOD-316

U.S.MAIL

Commanding Officer
Code L14
Naval Civil Engineering Laboratory
Port Hueneme, California 93043

DISTRIBUTION QUESTIONNAIRE

The Naval Civil Engineering Laboratory is revising its primary distribution lists.

SUBJECT CATEGORIES

1 **SHORE FACILITIES**
2 Construction methods and materials (including corrosion control, coatings)
3 Waterfront structures (maintenance/deterioration control)
4 Utilities (including power conditioning)
5 Explosives safety
6 Construction equipment and machinery
7 Fire prevention and control
8 Antenna technology
9 Structural analysis and design (including numerical and computer techniques)
10 Protective construction (including hardened shelters, shock and vibration studies)
11 Soil/rock mechanics
13 BEQ
14 Airfields and pavements
15 **ADVANCED BASE AND AMPHIBIOUS FACILITIES**
16 Base facilities (including shelters, power generation, water supplies)
17 Expedient roads/airfields/bridges
18 Amphibious operations (including breakwaters, wave forces)
19 Over-the-Beach operations (including containerization, materiel transfer, lighterage and cranes)
20 POL storage, transfer and distribution
24 **POLAR ENGINEERING**
24 Same as Advanced Base and Amphibious Facilities, except limited to cold-region environments
28 **ENERGY/POWER GENERATION**
29 Thermal conservation (thermal engineering of buildings, HVAC systems, energy loss measurement, power generation)
30 Controls and electrical conservation (electrical systems, energy monitoring and control systems)
31 Fuel flexibility (liquid fuels, coal utilization, energy from solid waste)
32 Alternate energy source (geothermal power, photovoltaic power systems, solar systems, wind systems, energy storage systems)
33 Site data and systems integration (energy resource data, energy consumption data, integrating energy systems)
34 **ENVIRONMENTAL PROTECTION**
35 Solid waste management
36 Hazardous/toxic materials management
37 Wastewater management and sanitary engineering
38 Oil pollution removal and recovery
39 Air pollution
40 Noise abatement
44 **OCEAN ENGINEERING**
45 Seafloor soils and foundations
46 Seafloor construction systems and operations (including diver and manipulator tools)
47 Undersea structures and materials
48 Anchors and moorings
49 Undersea power systems, electromechanical cables, and connectors
50 Pressure vessel facilities
51 Physical environment (including site surveying)
52 Ocean-based concrete structures
53 Hyperbaric chambers
54 Undersea cable dynamics

TYPES OF DOCUMENTS

85 Techdata Sheets
86 Technical Reports and Technical Notes
82 NCEL Guide & Updates
☐ None—remove my name
83 Table of Contents & Index to TDS
91 Physical Security

PLEASE HELP US PUT THE ZIP IN YOUR MAIL! ADD YOUR FOUR NEW ZIP DIGITS TO YOUR LABEL (OR FACSIMILE), STAPLE INSIDE THIS SELF-MAILER, AND RETURN TO US.

(fold here)

DEPARTMENT OF THE NAVY

NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043-5003

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300
1 IND-NCEL 2700/4 (REV 12-73)
0930-LL-L70-0044

POSTAGE AND FEES PAID
DEPARTMENT OF THE NAVY
DOD-316

U.S.MAIL

Commanding Officer
Code L14
Naval Civil Engineering Laboratory
Port Hueneme, California 93043-5003

END

FILMED

2-85

DTIC